AD-A068 456 GRUMMAN AEROSPACE CORP BETHPAGE N Y F/G 1/3

ADVANCED COMPOSITE WING COVER-TO-SUBSTRUCTURE ATTACHMNET (CTSA)--ETC(U)

JAN 79 C CACHO-NEGRETE, H FORSCH, G CONCANNON F33615-77-C-3071

UNCLASSIFIED AFFDL-TR-78-190 NL

1 OF 2

ADA 068456

LEVEL

AFFDL-TR-78-190

ADVANCED COMPOSITE WING COVER-TO-SUBSTRUCTURE ATTACHMENT (CTSA) DEVELOPMENT PROGRAM

Grumman Aerospace Corporation
Bethpage, New York 11714

January 1979

TECHNICAL REPORT AFFDL-TR-78-190

Final Report for Period July 1977 - November 1978

Approved for public release;
distribution unlimited

AIR FORCE FLIGHT DYNAMICS LABORATORY
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
AERONAUTICAL SYSTEMS DIVISION
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

NOTICE

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever, and the fact that the government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implications or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

This technical report has been reviewed and is approved for publication.

Charles L. Ramsey
Charles L. Ramsey
Project Engineer
AFFDL/FBS

Francis J. Janik, Jr.
Francis J. Janik, Jr., Chief
Structural Concepts Branch
Structural Mechanics Division

FOR THE COMMANDER

Ralph L. Kuster, Jr.
Ralph L. Kuster, Jr., Colonel, USAF
Chief, Structural Mechanics Division

If your address has changed, if you wish to be removed from our mailing list, or if the addressee is no longer employed by your organization please notify AFFDL/FBS, W-P AFB, OH 45433 to help us maintain a current mailing list.

Copies of this report should not be returned unless return is required by security considerations, contractual obligations, or notice on a specified document.

AIR FORCE/56780/17 April 1979 — 120

19 **REPORT DOCUMENTATION PAGE**

READ INSTRUCTIONS BEFORE COMPLETING FORM

18
1. REPORT NUMBER
AFFDL-TR-78-190

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER
9

6
4. TITLE (and Subtitle)
ADVANCED COMPOSITE WING COVER-TO-SUBSTRUCTURE ATTACHMENT (CTSA) DEVELOPMENT PROGRAM,

5. TYPE OF REPORT & PERIOD COVERED
FINAL TECHNICAL REPORT, JUL [redacted] 77-[redacted] NOV [redacted] 78

6. PERFORMING ORG. REPORT NUMBER

10
7. AUTHOR(s)
C. CACHO-NEGRETE, G. CONCANNON
H. FORSCH, R. CHALUS

8. CONTRACT OR GRANT NUMBER(s)
15 F33615-77-C-3071 new

9. PERFORMING ORGANIZATION NAME AND ADDRESS
GRUMMAN AEROSPACE CORPORATION
BETHPAGE, NEW YORK 11714

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
16 2401-03-13 17

11. CONTROLLING OFFICE NAME AND ADDRESS
STRUCTURAL MECHANICS DIVISION (FBS)
AIR FORCE FLIGHT DYNAMICS LABORATORY
WRIGHT PATTERSON AIR FORCE BASE, OH 45433

12. REPORT DATE
11 Jan 79

13. NUMBER OF PAGES

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)
12 160p.

15. SECURITY CLASS. (of this report)
UNCLASSIFIED

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)
Approved for public release;
distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES
Advanced Composites
Advanced Composite Wing Cover-To-Substructure Attachment (CTSA)
Exploratory Development Program

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)
Advanced Composite Wing Cover-To-Substructure Attachment (CTSA) graphite/epoxy, stitched lower cover, elimination of mechanical fasteners, integrally cured assemblies, thermoplastic sealing, through cover tows, sewn slug, sewn "Tee" spar cap, moisture conditioning, static/fatigue, translamina reinforcements.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)
This program was undertaken to develop and test wing design manufacturing and fuel sealing concepts that will eliminate the need of mechanical fasteners to attach the lower wing cover to the substructure. In addition, the ability to remove and reseal the thermoplastic bonded joint was demonstrated. The integrally cured Wing Cover-To-Spar Concepts have demonstrated great potential to reduce cost, increase structural efficiency, increase fuel sealing reliability and improve damage tolerance. Integral to this program was the development of analytical and fabrication techniques for translamina reinforced Wing Cover-To-Spar joints. The test wing box has successfully demonstrated the ability over

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

388 847

79 05 07 098

of a stitched and thermoplastically sealed lower wing cover to resist wing torsion and pressure loads both statically (RT and 270 F) and in fatigue (RT and 270 F). This volume reports the coupon designs, coupon manufacturing, coupon moisture conditioning, coupon test results, test box design, test box manufacturing, test box thermoplastic sealing and test box static and fatigue test results.

PREFACE

The work reported herein was performed under the sponsorship of the Air Force Flight Dynamics Laboratory, Structural Concepts Branch, Air Force Systems Command, Wright Patterson Air Force Base, Dayton, Ohio 45433. Mr. C. Ramsey, AFFDL/FBS is the Air Force Project Engineer.

The work was performed by the Advanced Composites Group of Grumman Aerospace Corporation, Bethpage, New York 11714 under Contract F33615-77-C-3071. The program was conducted between July 1977 and November 1978.

Key personnel associated with the program and their respective areas of responsibility are:

S. Dastin	Program Manager
H. Forsch	Project Engineer
C. Cacho-Negrete	Structural Design
L. Murrin	Structural Analysis
G. Concannon	Structural Mechanics
D. Sharp	Structural Mechanics
H. Borstell	Materials and Processes
R. Chalus	Structural Test
P. Donohue	Elements and Material Test
T. Johnson	Manufacturing

TABLE OF CONTENTS

TABLE OF CONTENTS (contd)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (contd)

LIST OF ILLUSTRATIONS (contd)

LIST OF ILLUSTRATIONS (Contd)

TABLES

SECTION I

INTRODUCTION AND SUMMARY

1.1 OBJECTIVE

The objective of the CTSA program was to develop and test wing design and manufacturing concepts that would eliminate the need for fasteners to attach the lower wing cover to the substructure. In addition, design and manufacturing concepts were developed and tested, which tended to reduce the number of fasteners required to attach the upper wing cover to the substructure and at the same time provide positive fuel sealing at this interface.

1.2 PROGRAM SCOPE

The program evaluated four concepts for the attachment of wing lower cover to substructure (see Fig. 1) and compared the test results from these specimens to a mechanically fastened joint designed to the same requirements. Various stitch materials were evaluated for the design concepts. Thermoplastic adhesives were also evaluated to provide repairable fuel sealing concepts for wing structures.

The most promising concept for fuel sealing and attachment was selected and utilized in the fabrication and test of a fuel-tight box. The test box was subjected to torsion and internal pressure both statically and in fatigue. The tests were performed at room temperature and at 270°F. The test box was used to demonstrate the ability to reseal a fuel leak and the removal and installation of the upper cover. An evaluation of the potential cost savings of these concepts over conventional assembly methods was also performed.

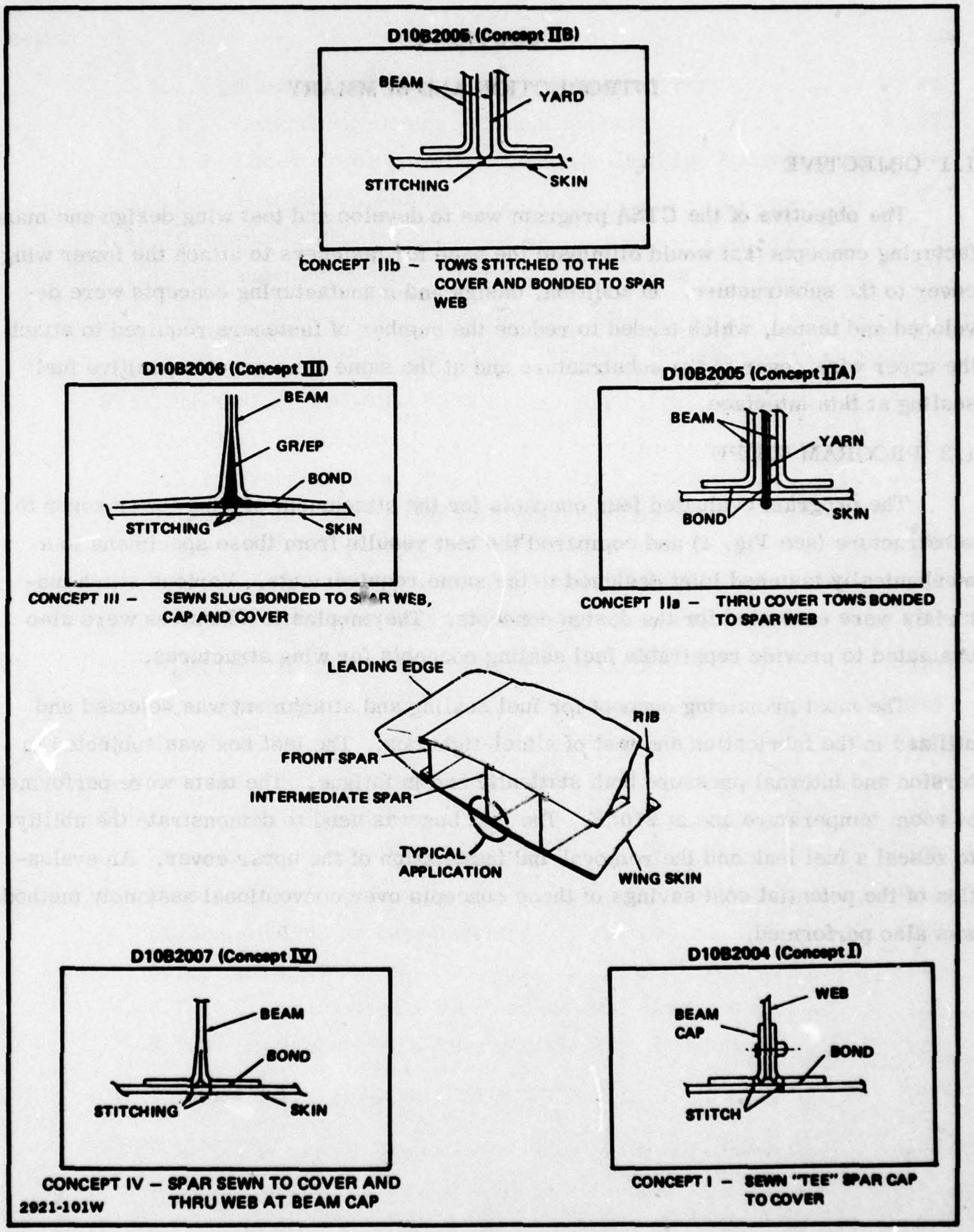


Fig. 1 CTSA Design Concepts

SECTION II

CONCEPTUAL DEVELOPMENT

2.1 CONFIGURATION SELECTION

The aircraft configuration selected to provide design data guidelines was the ATS configuration (Fig. 2) which resulted from the recently completed ATS studies. This mid-wing configuration features a through wing box multispar construction and incorporates an integral fuel tank for three quarters of the wing span.

The covers and substructure of the ATS wing consist of all graphite/epoxy, with a maximum cover thickness of approximately 0.336 in. As shown in Fig. 3, the spar spacing varies from a maximum at the root of 8.13 in. to 4 in. at the fuel tank closure. The wing thickness varies from a maximum of 8 in. at the root to 4 in. at the fuel tank closure.

The loads selected to design the various elements of this program are also based on this structural configuration. The shear loads used to design the spars are 1200 lb/in. ultimate with a required shear transfer from spar to cover of 1200 lb/in. ultimate. The cover laminate selected is a total of 64 plies with an orientation of 42 plies at 0^{o}, 6 plies at 90^{o}, and 16 plies at $\pm 45^{o}$ (42/6/16). The internal ultimate fuel pressure variation is shown in Fig. 4 and consists of an ultimate system pressure of 6 psi and a dynamic pressure resulting from a roll rate of 380^{o}/second ultimate that peaks the pressure to approximately 85 psi ultimate at the outboard tank closure.

As a result of these fuel pressure loads, the cover-to-spar-cap load intensity varies from approximately 50 lb/in. at the centerline to 340 lb/in. at the extreme outboard tank closure. The actual ultimate load intensities at the various stations are shown in Fig. 4.

2.2 STITCHING CONCEPTS

The stitching concepts selected for evaluation in this program are shown in Fig. 5. These concepts included two baseline mechanically attached configurations (a "T" cap and an angle cap) and four stitching concepts. The stitching concepts were the following:

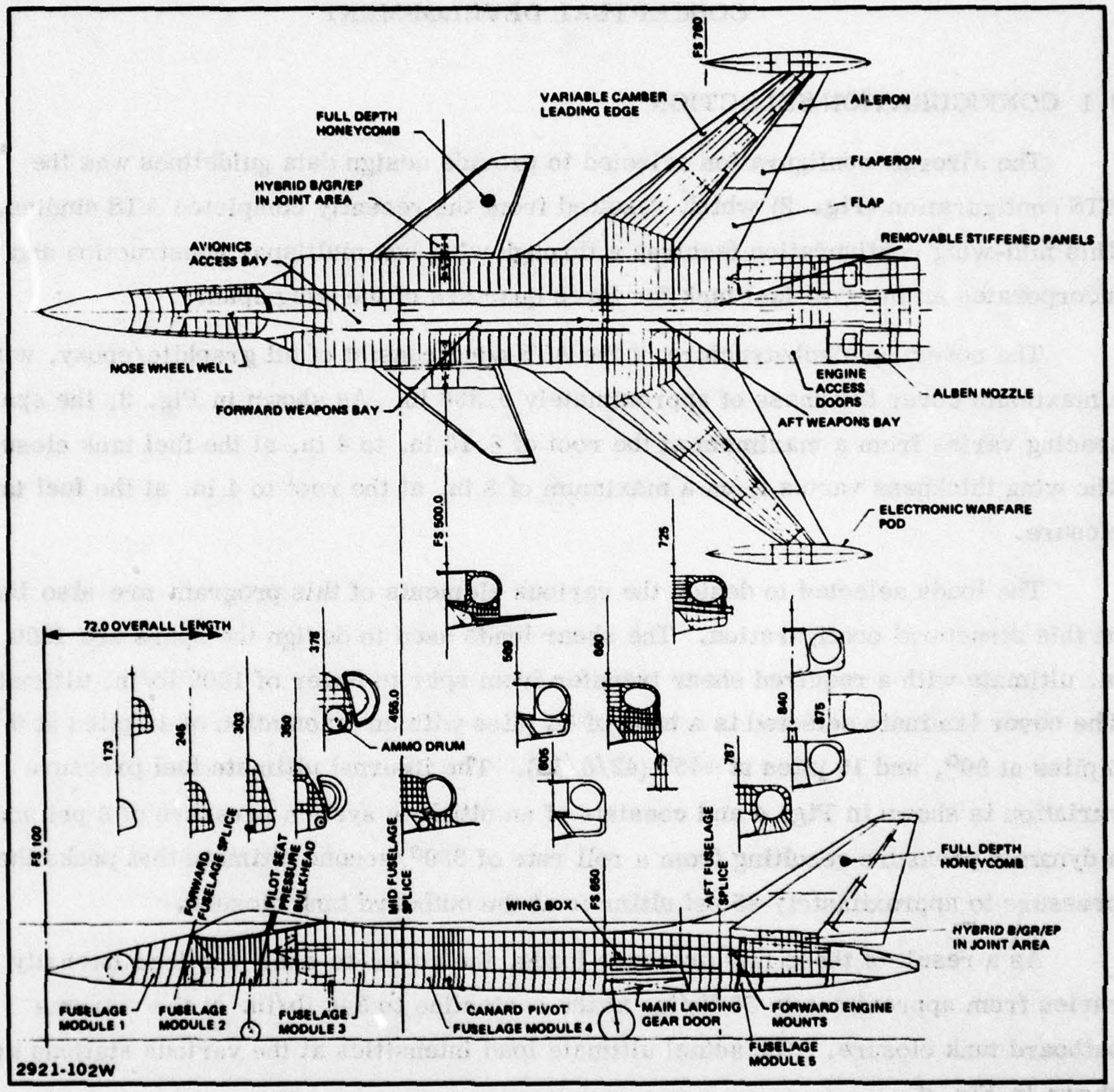


Fig. 2 Selected ATS Structural Arrangement - Advanced Composites

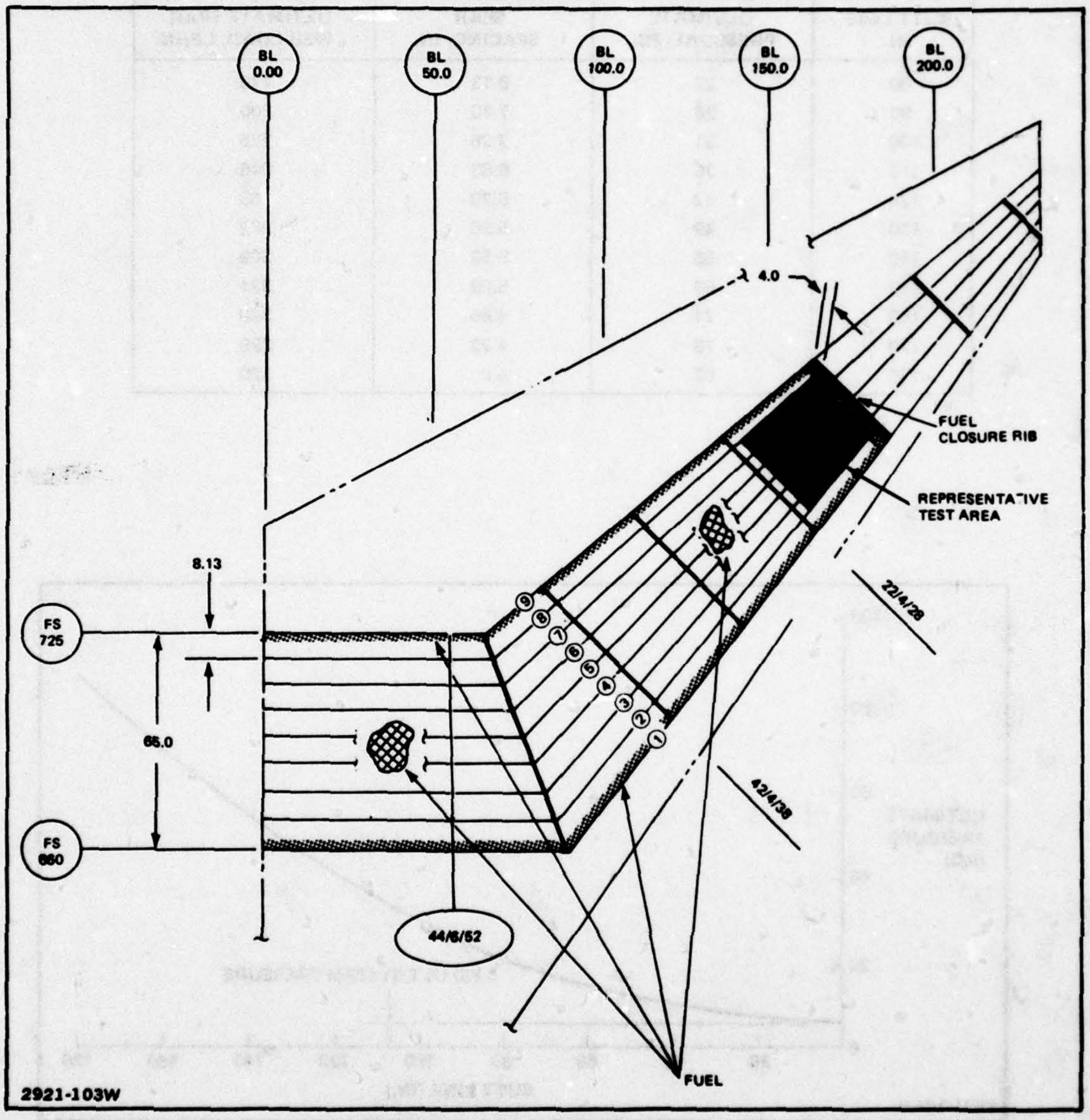


Fig. 3 "ATS" Preliminary Wing Configuration

Ultimate Spar Web Load Due to Fuel Pressure

BUTT LINE IN.	ULTIMATE PRESSURE, PSI	SPAR SPACING, IN.	ULTIMATE SPAR WEB LOAD, LB/IN.
80	22	8.13	179
90	26	7.70	200
100	31	7.26	225
110	36	6.83	246
120	42	6.39	268
130	49	5.96	292
140	56	5.52	309
150	63	5.09	321
160	71	4.65	330
170	78	4.22	329
175	82	4.0	328

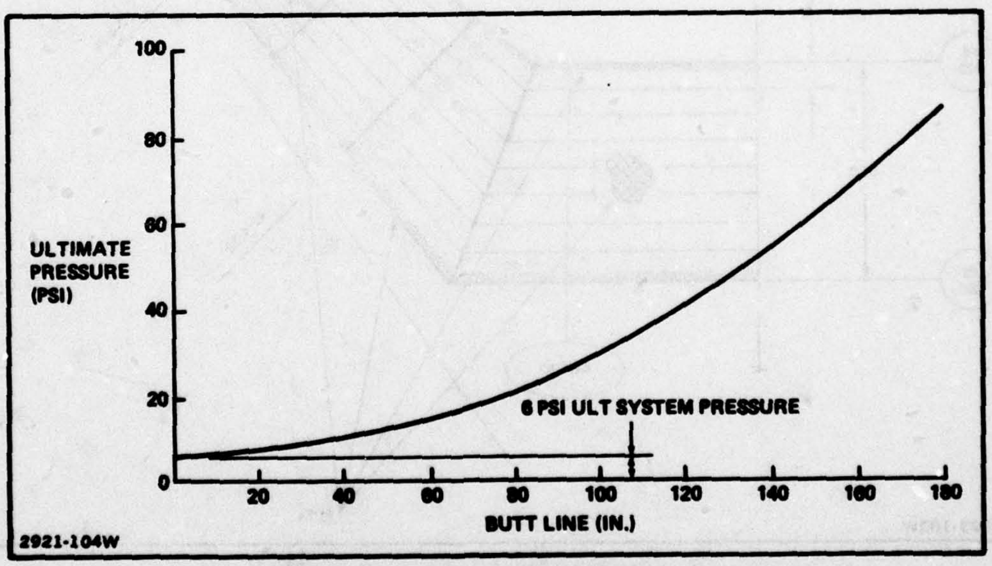


Fig. 4 "ATS" Wing-Preliminary Ultimate Pressures (roll rate = 380°/second)

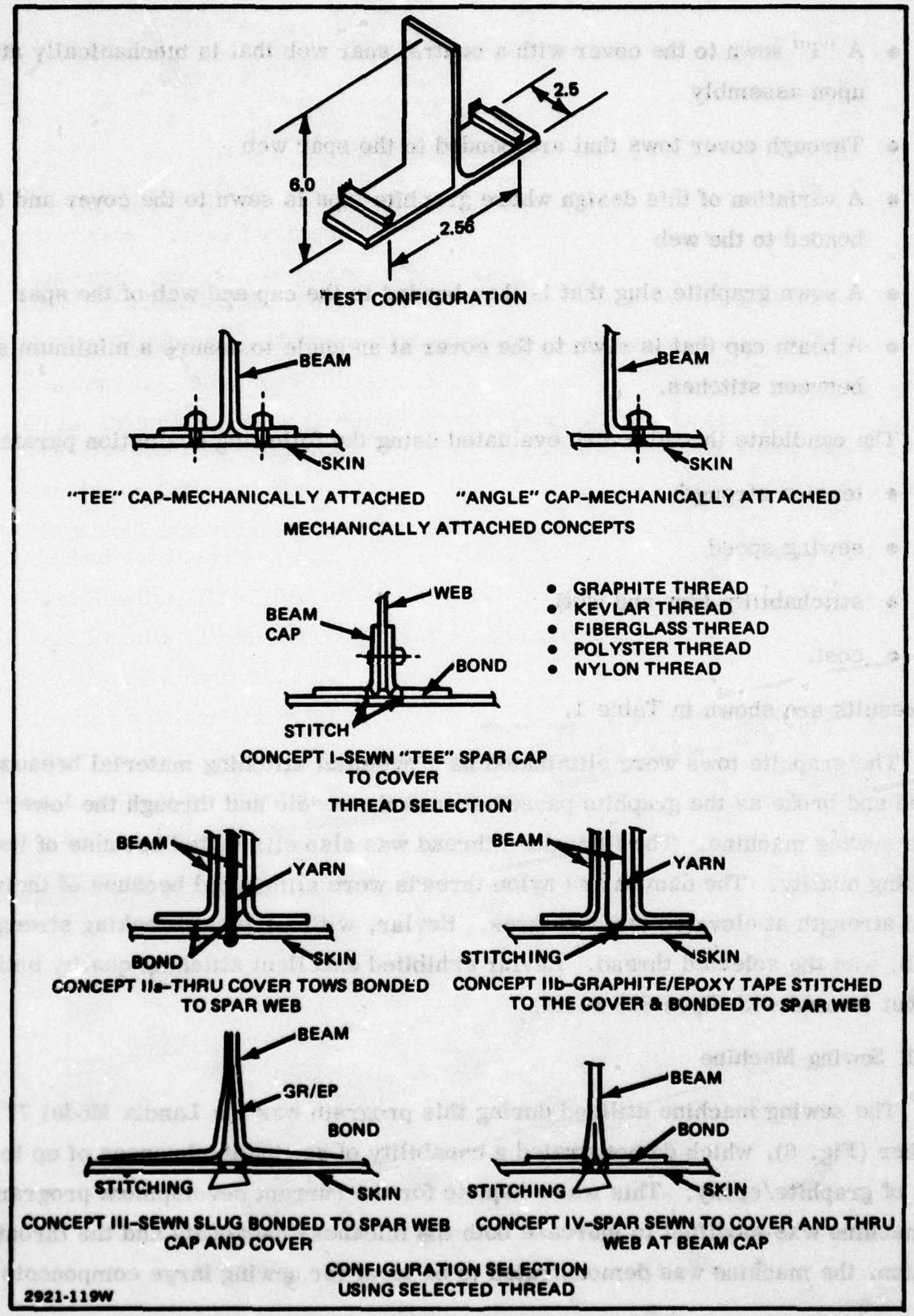


Fig. 5. Cover-to-Substructure Design Concepts

- A "T" sewn to the cover with a central spar web that is mechanically attached upon assembly
- Through cover tows that are bonded to the spar web
- A variation of this design where graphite tape is sewn to the cover and then bonded to the web
- A sewn graphite slug that is then bonded to the cap and web of the spar
- A beam cap that is sewn to the cover at an angle to assure a minimum span between stitches.

The candidate threads were evaluated using the following evaluation parameters:

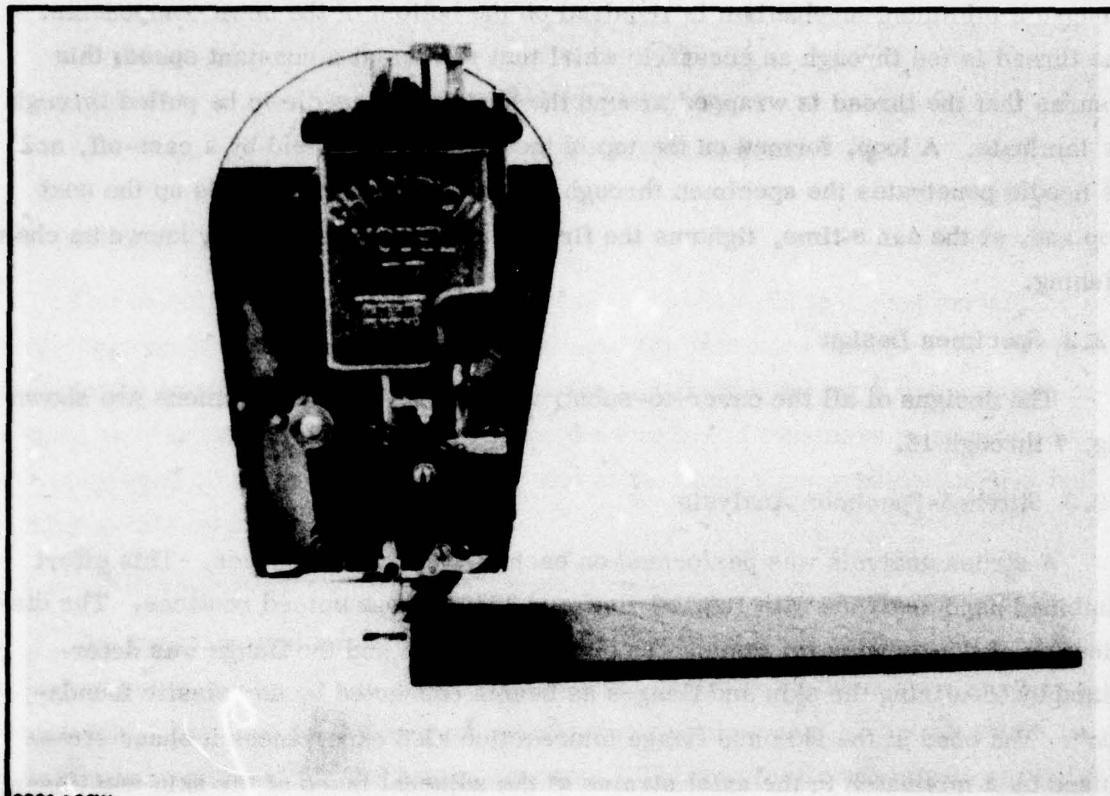
- tension strength
- sewing speed
- stitchability (dry and wet)
- cost.

The results are shown in Table 1.

The graphite tows were eliminated as a potential stitching material because they frayed and broke as the graphite passed across the needle and through the lower whirl of the sewing machine. The fiberglass thread was also eliminated because of its poor stitching quality. The dacron and nylon threads were eliminated because of their reduced strength at elevated temperatures. Kevlar, with a typical breaking strength of 120 lb, was the selected thread. Kevlar exhibited excellent stitching quality both dry and wet (coated with Epon 828 resin).

2.2.1 Sewing Machine

The sewing machine utilized during this program was the Landix Model 77 Chain Stitcher (Fig. 6), which demonstrated a capability of sewing thicknesses of up to 90 plies of graphite/epoxy. This was adequate for the current development program, but the machine was modified to increase both the thickness capability and the throat. In addition, the machine was demonstrated to be ideal for sewing large components



2921-192W

Fig. 6 Landis Model 77 Chain Stitcher

TABLE 1
CANDIDATE THREAD EVALUATION

THREAD	SEWING SPEED	STRENGTH (LB)	STITCHABILITY	COST ($/LB)
DACRON	SLOW (SLOW)	70*	EXCELLENT (FAIR)	10
FIBERGLASS	SLOW (SLOW)	80*	POOR (FAIR)	3
GRAPHITE (1000 ENDS	SLOW (SLOW)	24**	POOR (POOR)	45
KEVLAR	SLOW (SLOW)	120*	EXCELLENT (EXCELLENT)	20
NYLON	SLOW (SLOW)	77**	EXCELLENT (EXCELLENT)	4

NOTE:

(W) = WET

* MANUFACTURER'S

** GRUMMAN'S TEST VALUE

2921-105W

because a minimum mechanism is required on the bottom of the sewn components. The thread is fed through an eccentric whirl that rotates at a constant speed; this assures that the thread is wrapped around the hook of the needle to be pulled through the laminate. A loop, formed on the top of the specimen, is held by a cast-off, and the needle penetrates the specimen through the existing loop as it pulls up the next loop and, at the same time, tightens the first loop. This is commonly known as chain stiching.

2.2.2 Specimen Design

The designs of all the cover-to-substructure attachment specimens are shown in Fig. 7 through 16.

2.2.3 Stitched-Specimen Analysis

A stress analysis was performed on each of the specimen types. This effort combined hand analyses with Hewlett Packard 9830A programmed routines. The distribution of the flatwise tension stress between the skin and the flange was determined by idealizing the skin and flanges as beams connected by an "elastic foundation". The bond at the skin and flange intersection also experiences a shear stress caused by a mismatch in the axial strains at the adjacent faces of the skin and flange; the skin has a tensile strain at the joint face due to the bending moment that imposes zero slope on the skin at the joint centerline, while the flange has zero moment at the heel. The resultant shear stress in the bond was calculated using a "shear lag" model per Ref. 1. The graphite/epoxy allowables were obtained from Ref. 2.

2.2.4 Applicability to Production of Full Scale Wings

The manufacturing processes required to successfully stitch composite assemblies were investigated. The known manufacturing requirements are:

- Sew through a compacted but uncured laminate 0.7 inch thick
- Follow a straight line on a curved surface, i.e., wing element line
- Heat the area being sewn between 130° F and 150° F
- Compensate and control thread tension to allow for changing thickness, i.e., wing thicker inboard than outboard

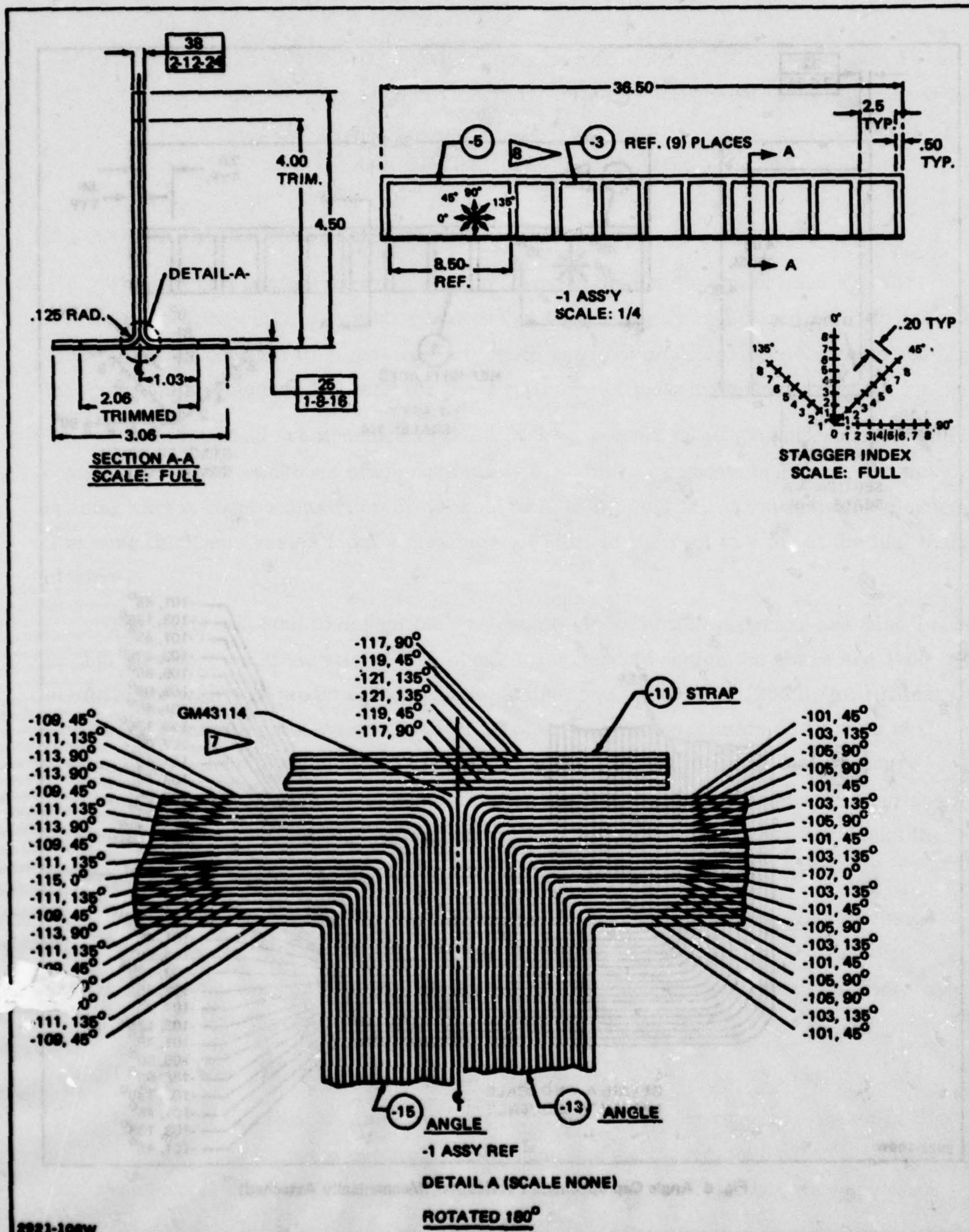


Fig. 7 "T" Cap Specimen Fabrication (Mechanically Attached)

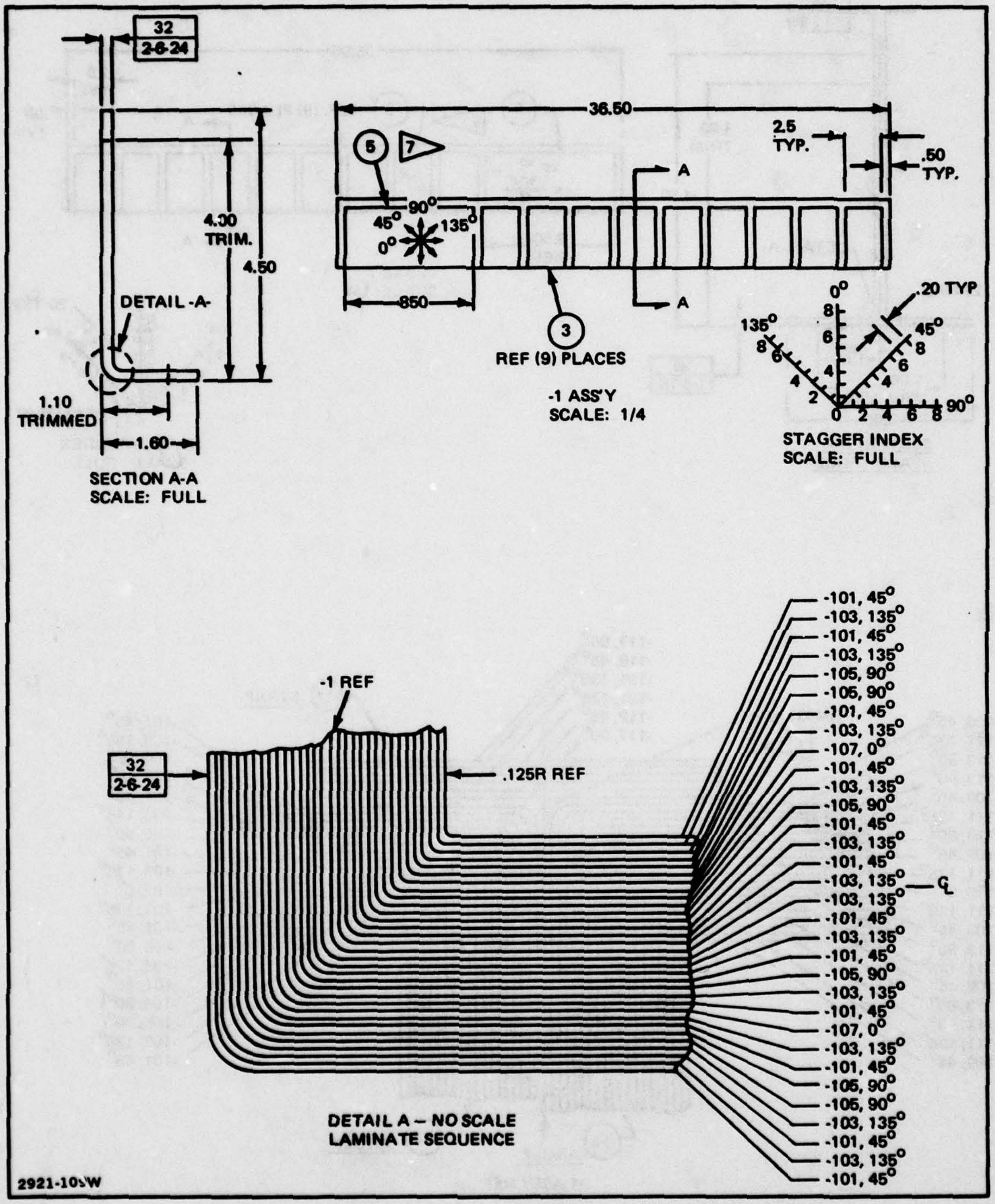


Fig. 8 Angle Cap Specimen Fabrication (Mechanically Attached)

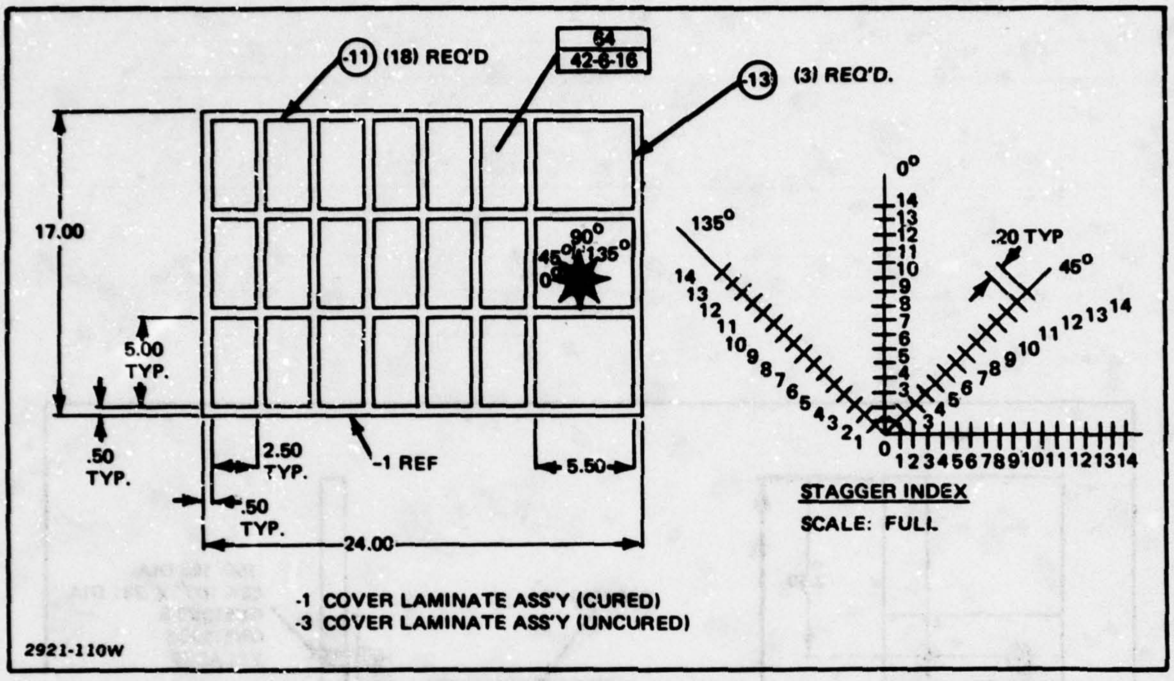


Fig. 9 Cover Laminate Fabrication

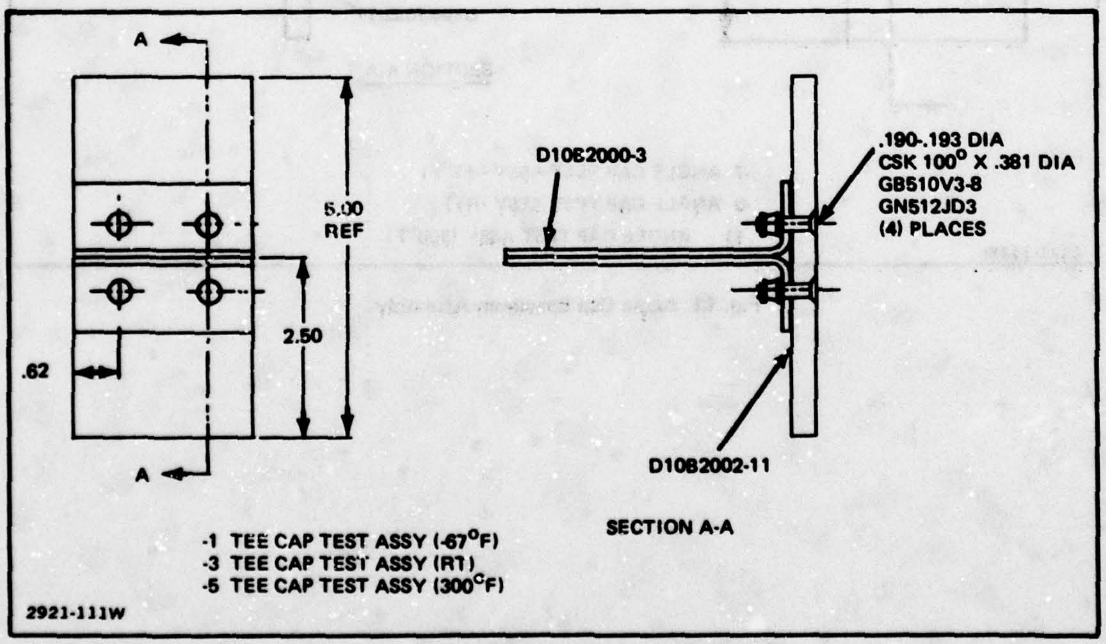


Fig. 10 "T" Cap Specimen Assembly

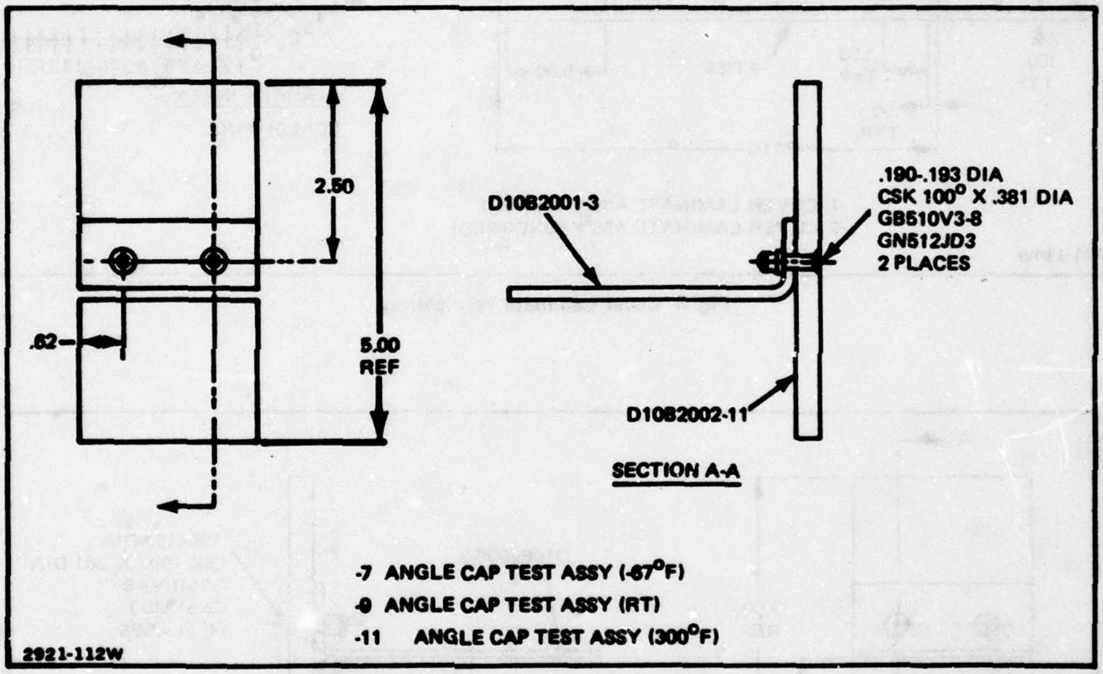
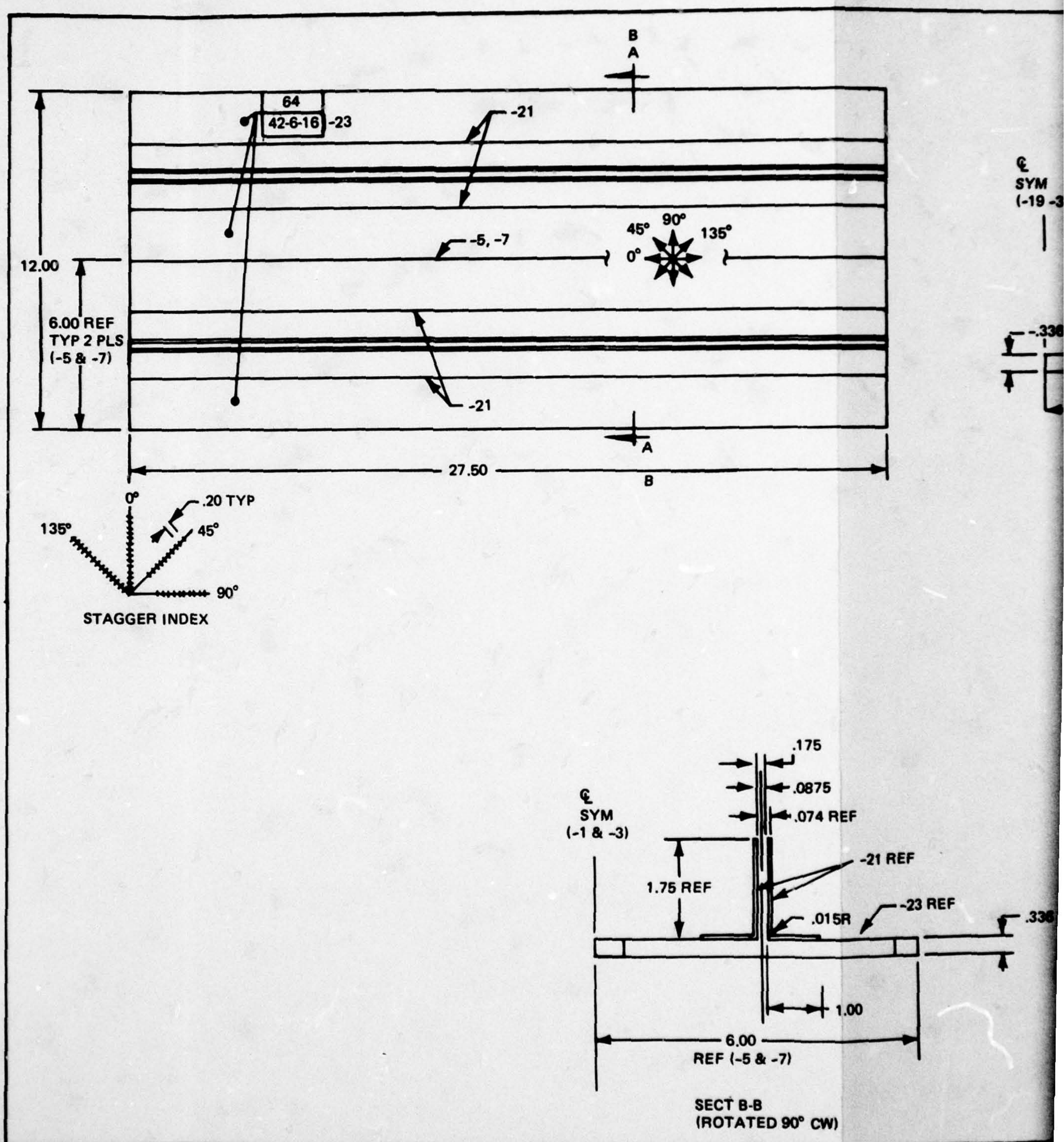


Fig. 11 Angle Cap Specimen Assembly



B
A
64
42-6-16
-23
-21
12.00
6.00 REF
TYP 2 PLS
(-5 & -7)
45°
90°
135°
0°
-5, -7
-21
A
27.50
B
0°
.20 TYP
135°
45°
90°
STAGGER INDEX
.175
.0875
.074 REF
℄
SYM
(-1 & -3)
1.75 REF
-21 REF
-23 REF
.015R
.336
1.00
6.00
REF (-5 & -7)
SECT B-B
(ROTATED 90° CW)
℄
SYM
(-19 -3
.336

Fig. 12

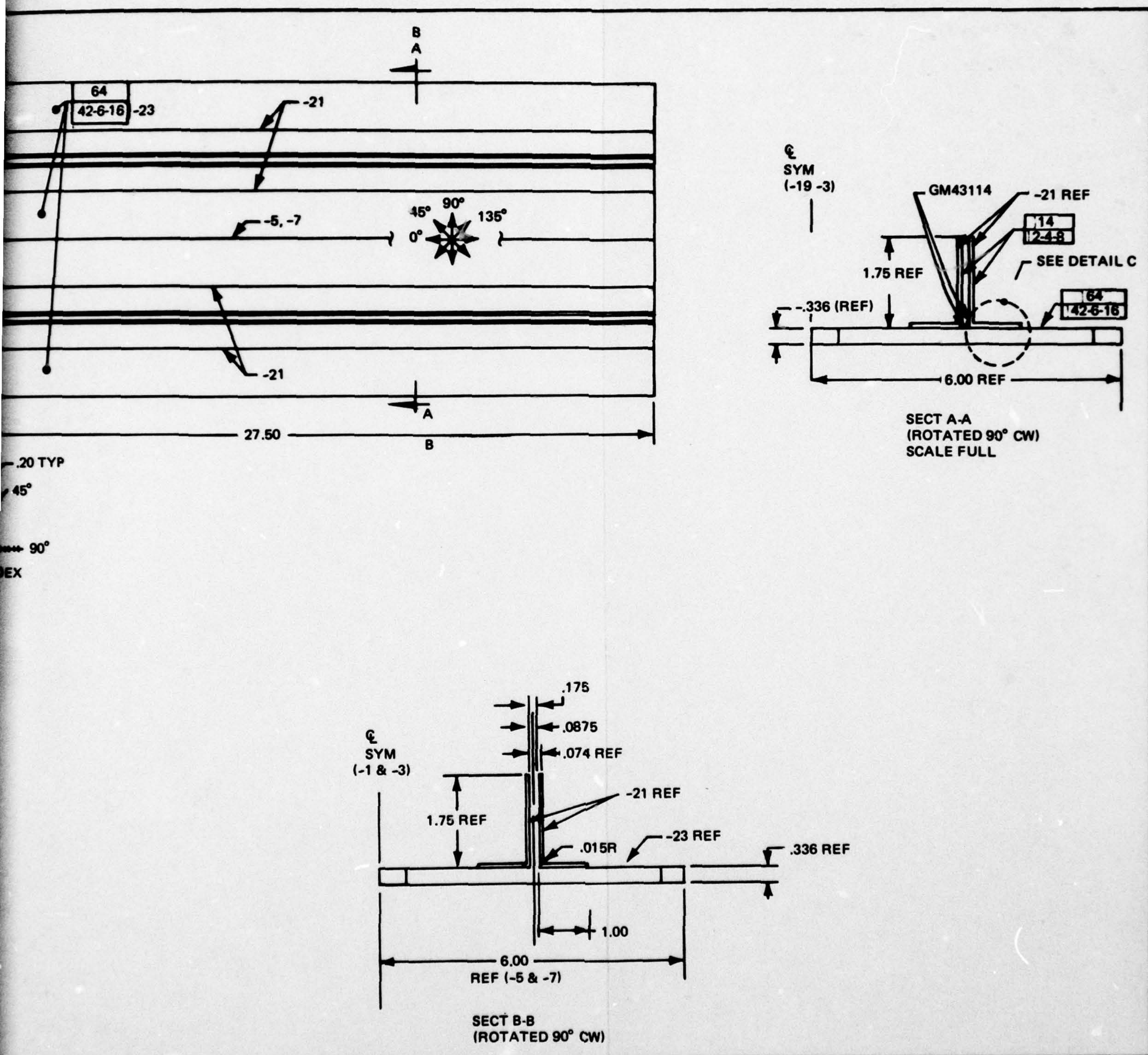


Fig. 12 Bonded "T" Cap Concept I – Control

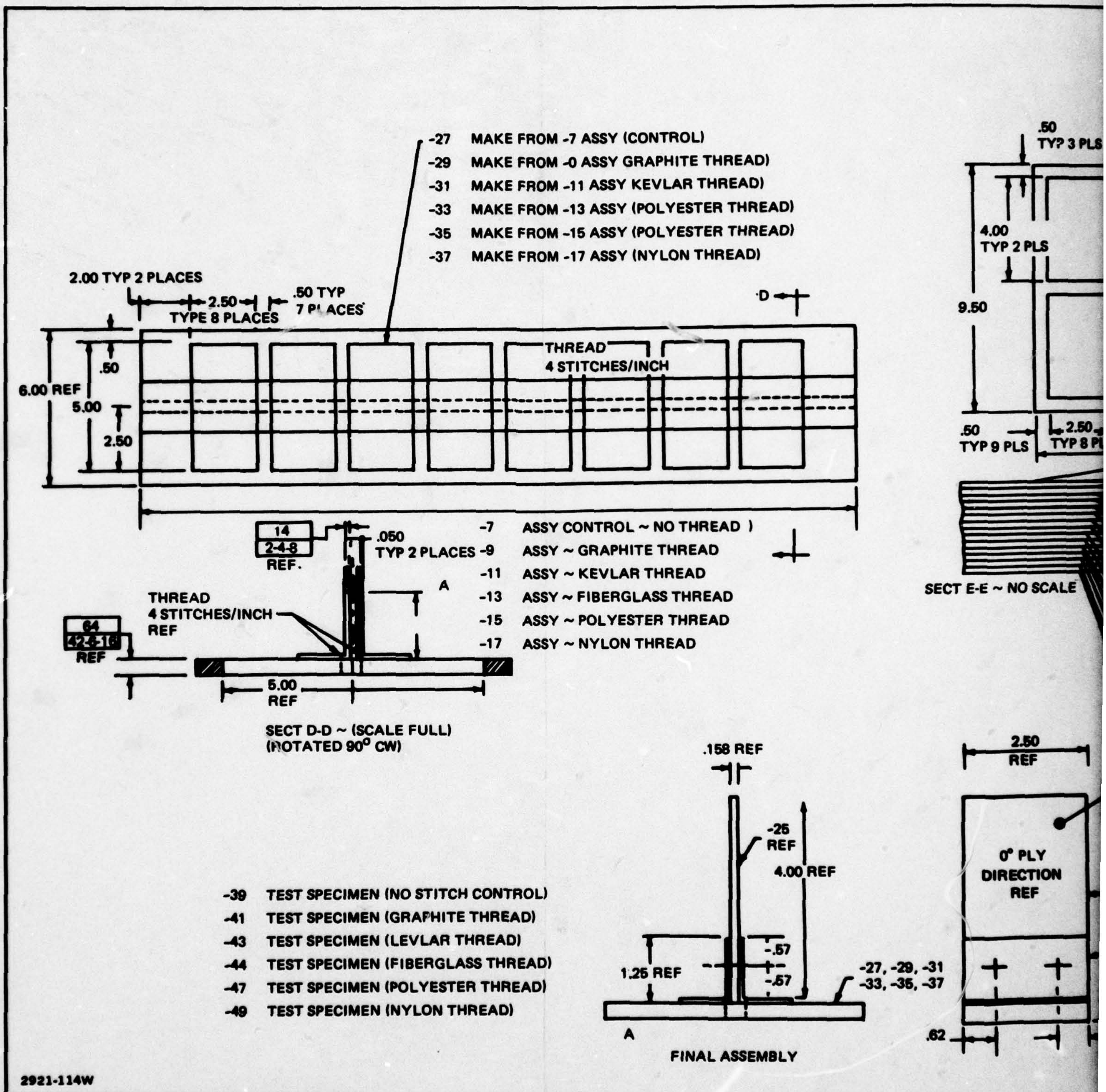
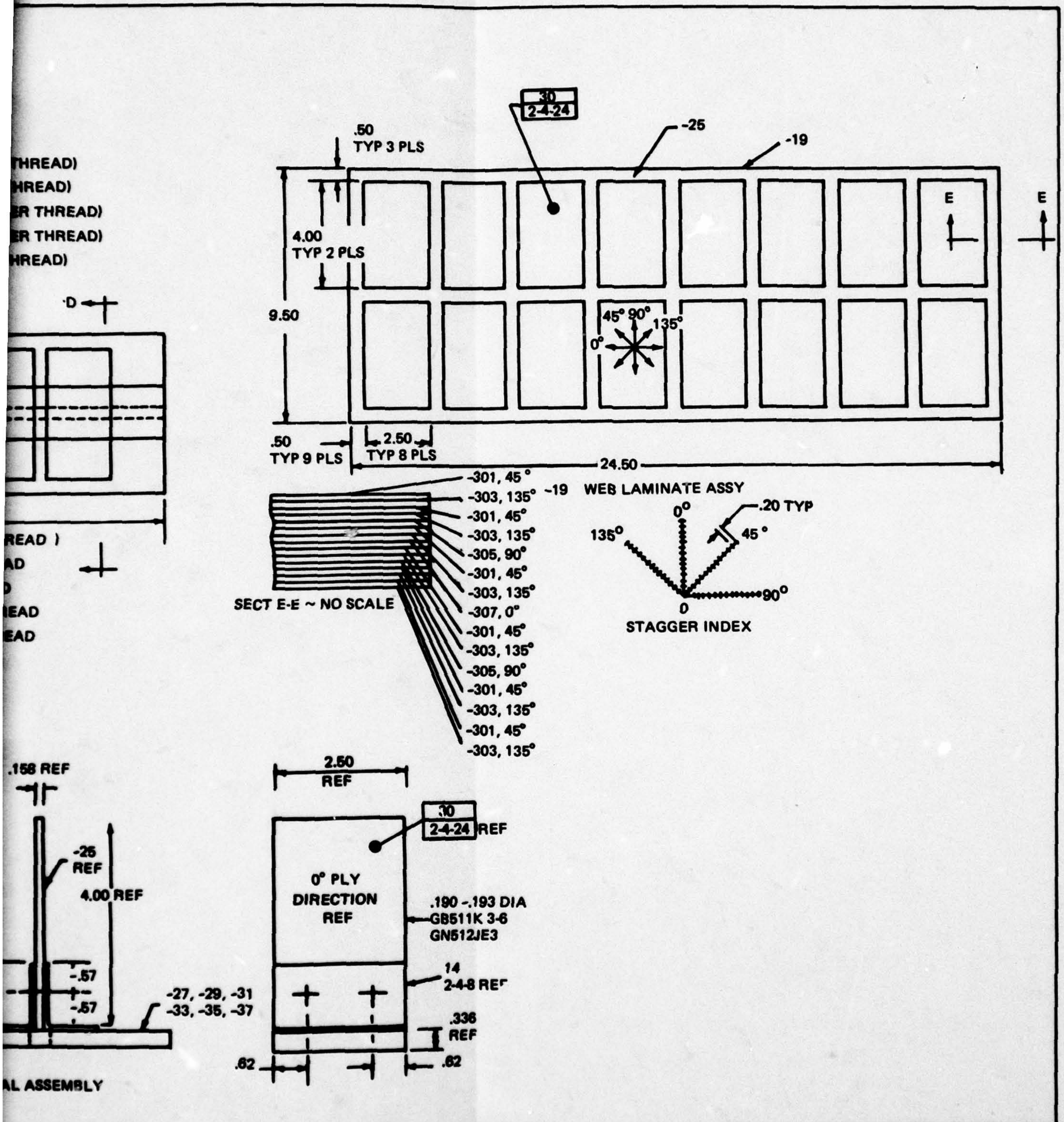


Fig. 13 Sewn "T" Cap Concept I



THREAD)
HREAD)
ER THREAD)
ER THREAD)
HREAD)
D
READ)
AD
D
EAD
EAD
.30
2-4-24
-25
-19
.50
TYP 3 PLS
4.00
TYP 2 PLS
9.50
E
E
45° 90°
135°
0°
.50
TYP 9 PLS
2.50
TYP 8 PLS
24.50
-301, 45°
-303, 135°
-19
WEB LAMINATE ASSY
-301, 45°
-303, 135°
-305, 90°
-301, 45°
-303, 135°
-307, 0°
-301, 45°
-303, 135°
-305, 90°
-301, 45°
-303, 135°
-301, 45°
-303, 135°
SECT E-E ~ NO SCALE
.20 TYP
0°
135°
45°
90°
0
STAGGER INDEX
.158 REF
-25
REF
4.00 REF
-.57
-.57
-27, -29, -31
-33, -35, -37
AL ASSEMBLY
2.50
REF
.30
2-4-24
REF
0° PLY
DIRECTION
REF
.190 -.193 DIA
GB511K 3-6
GN512JE3
14
2-4-8 REF
.336
REF
.62
.62

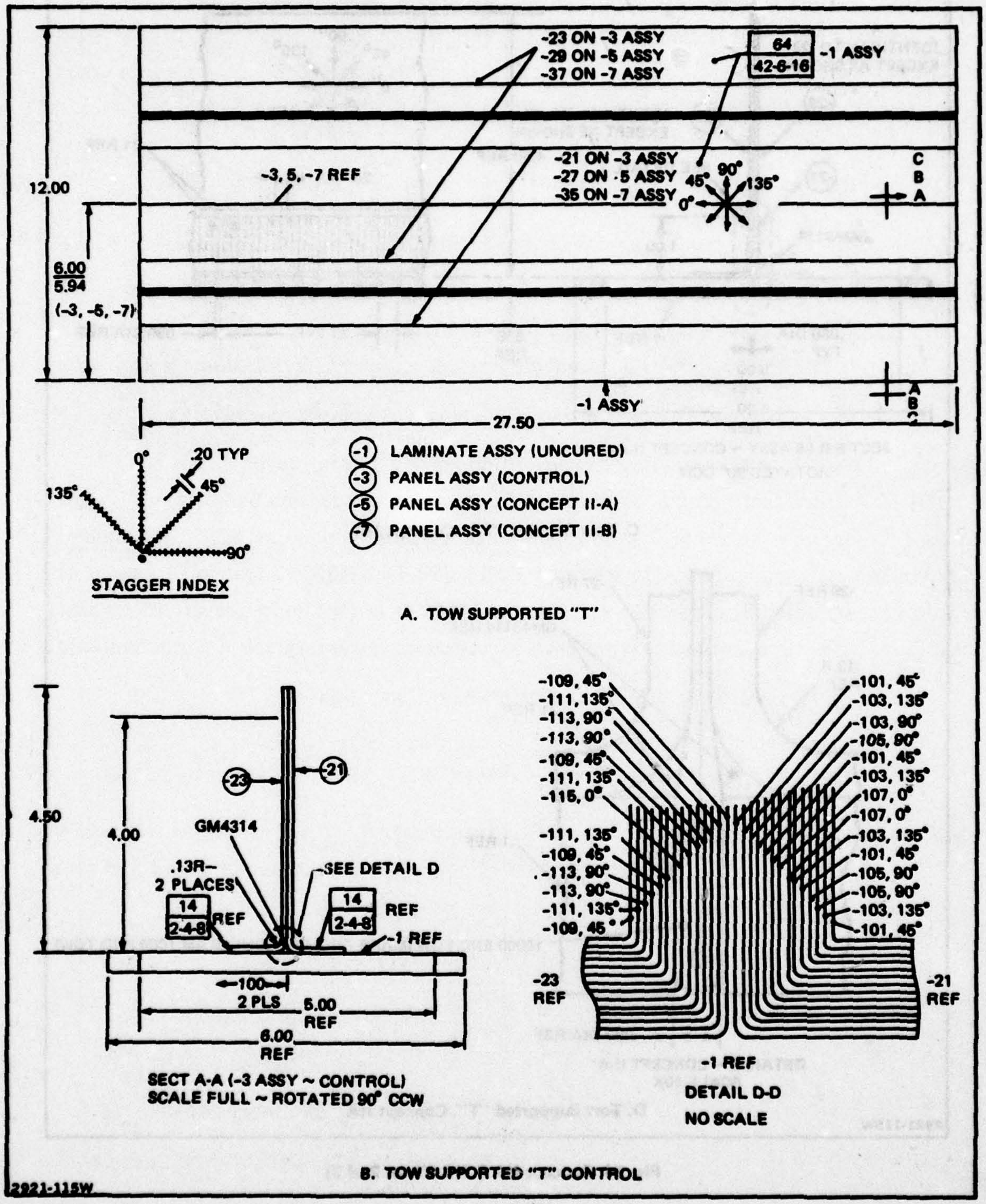
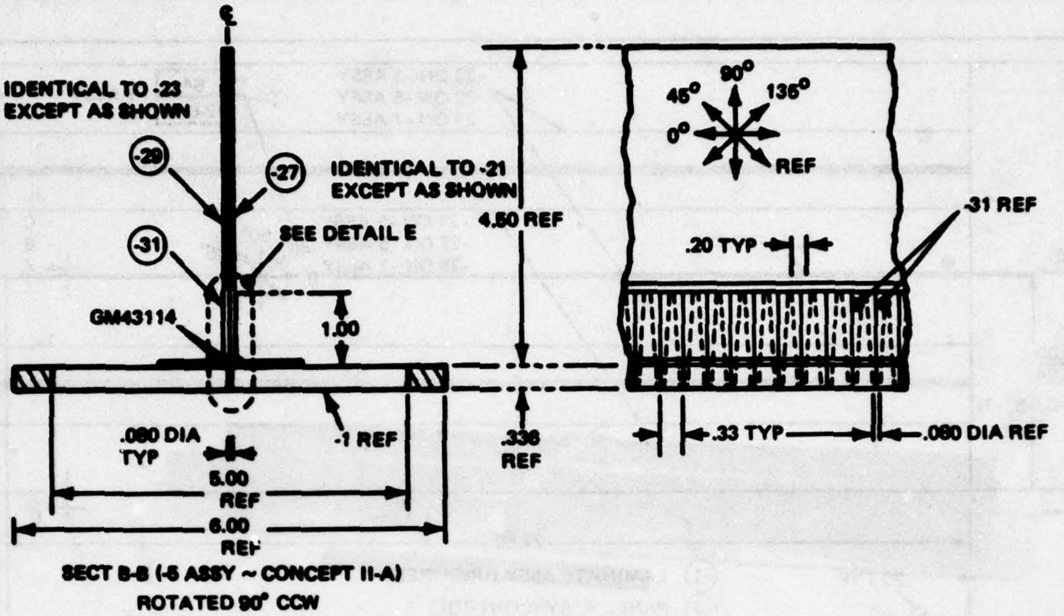
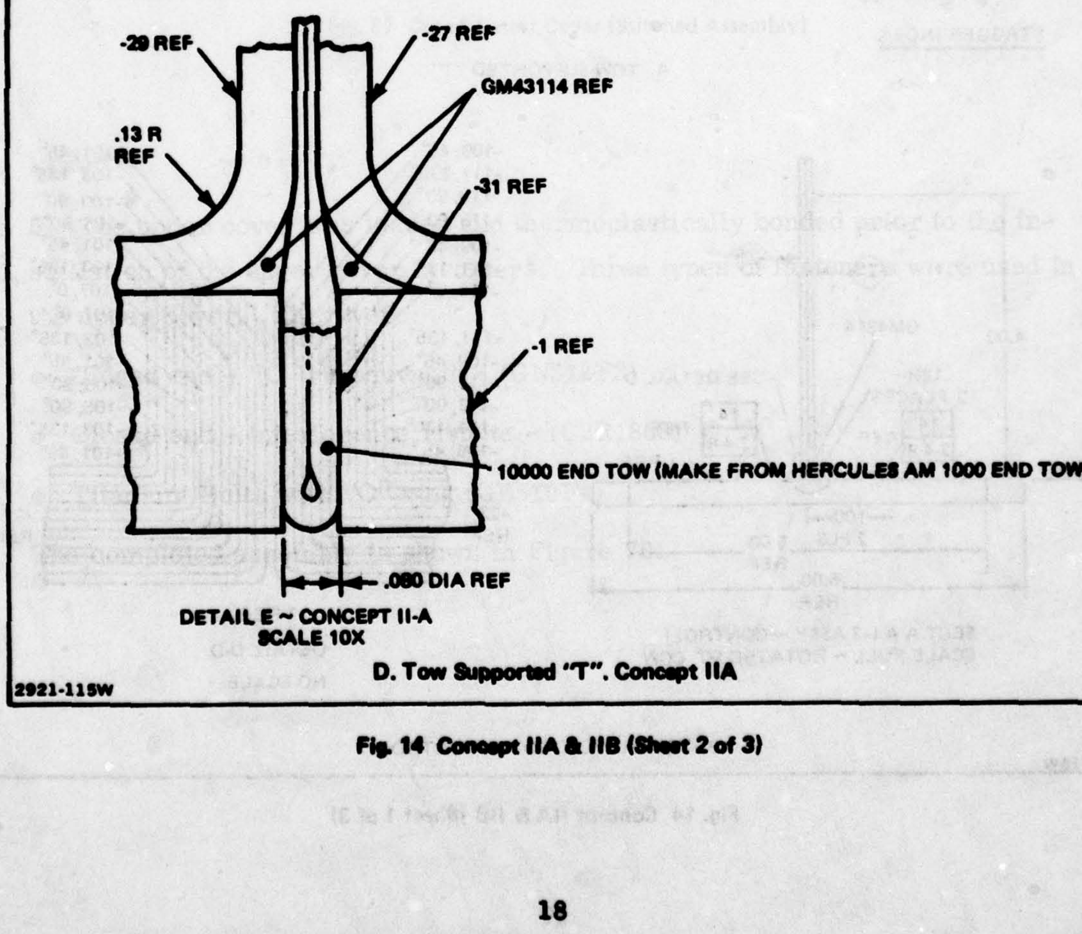


Fig. 14 Concept IIA & IIB (Sheet 1 of 3)

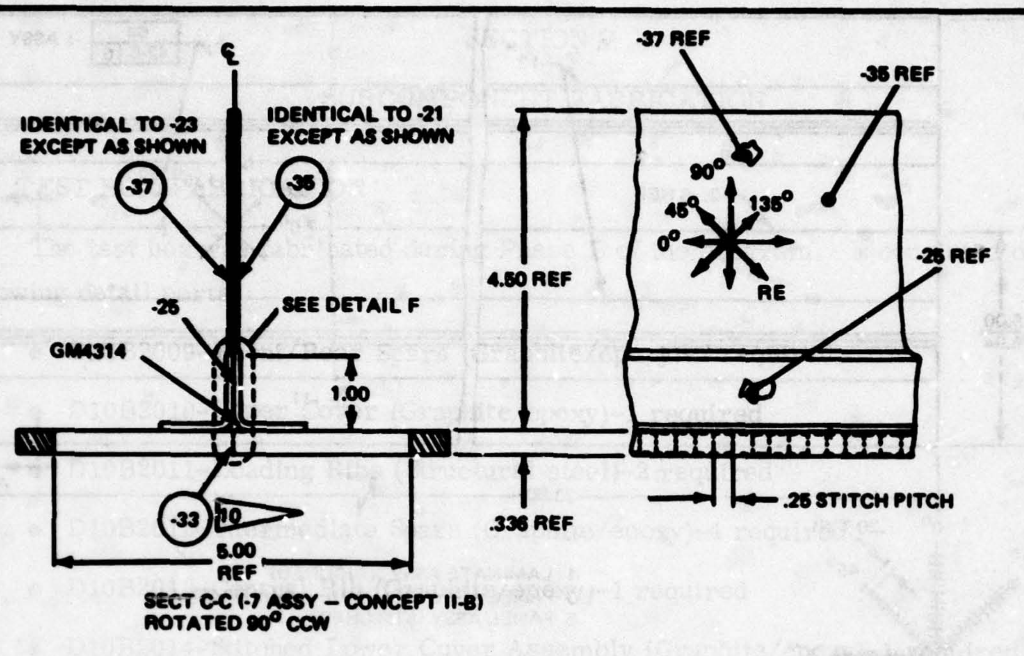


C. Tow Support "T". Concept IIA

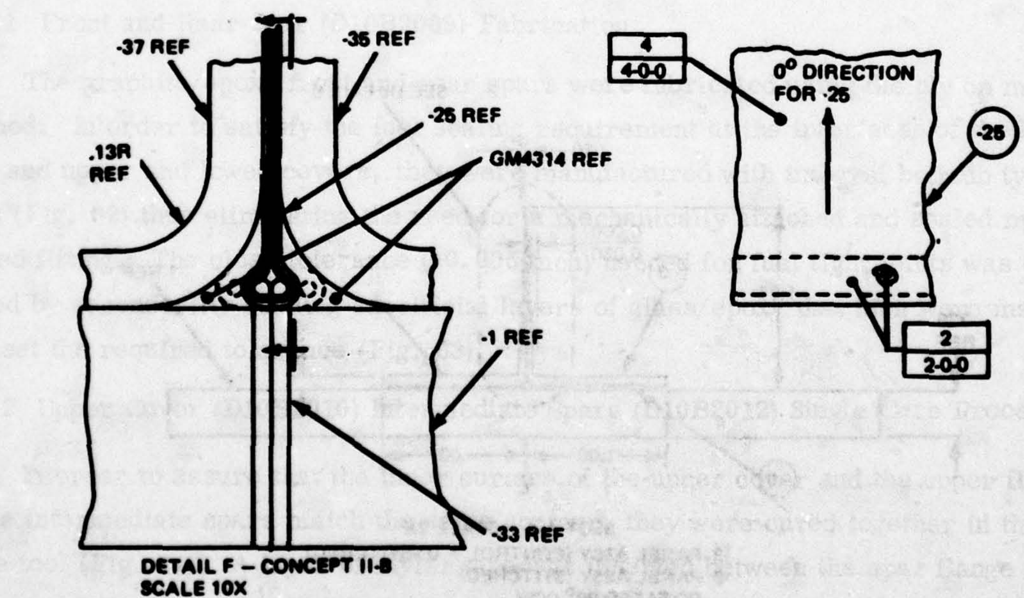


D. Tow Supported "T". Concept IIA

Fig. 14 Concept IIA & IIB (Sheet 2 of 3)



E. Graphite/Epoxy Tape/Stitched (Concept IIB)



2921-115W

F. Graphite/Epoxy Tape/Stitched (Concept IIB)

Fig. 14 Concept IIA & IIB (Sheet 3 of 3)

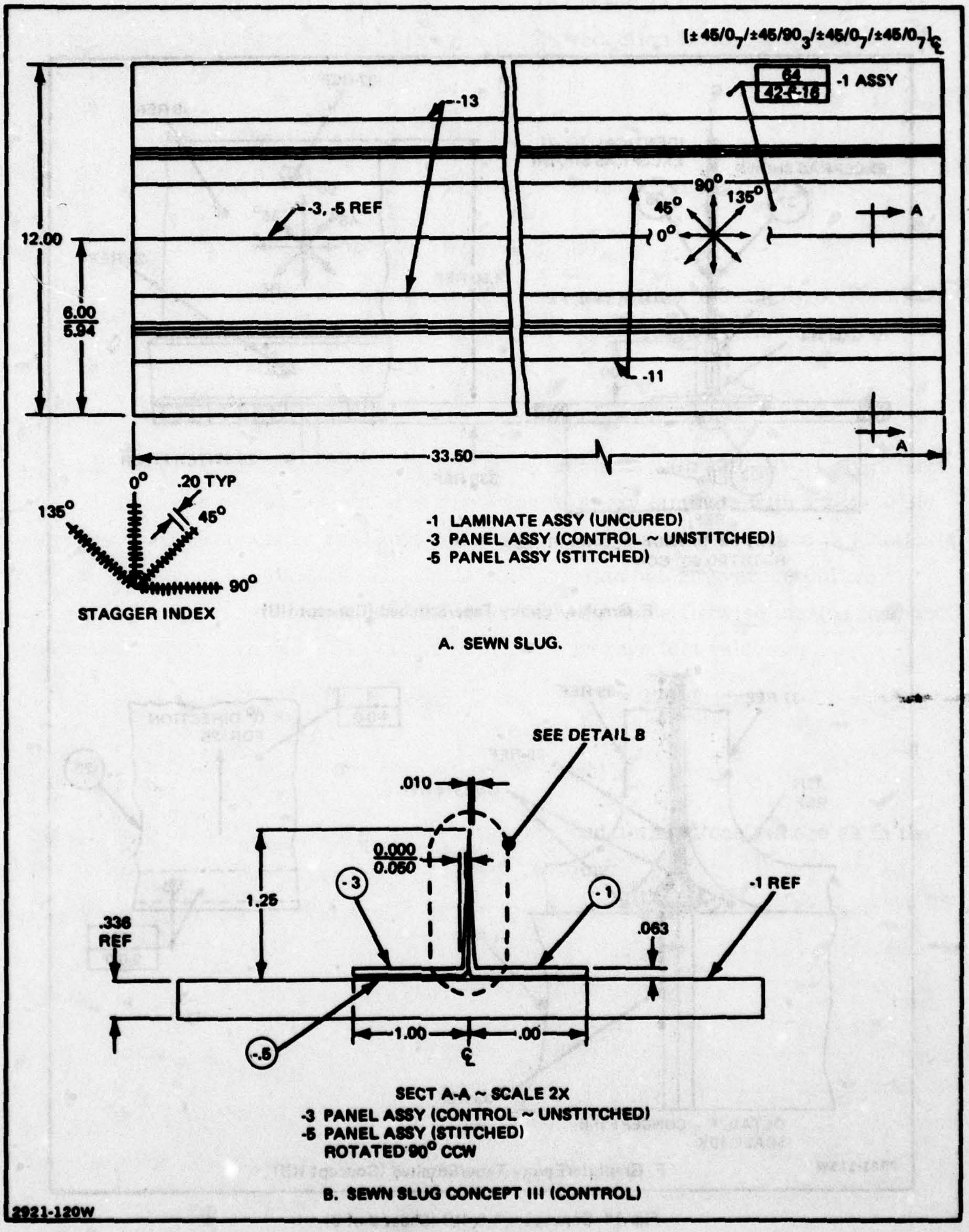
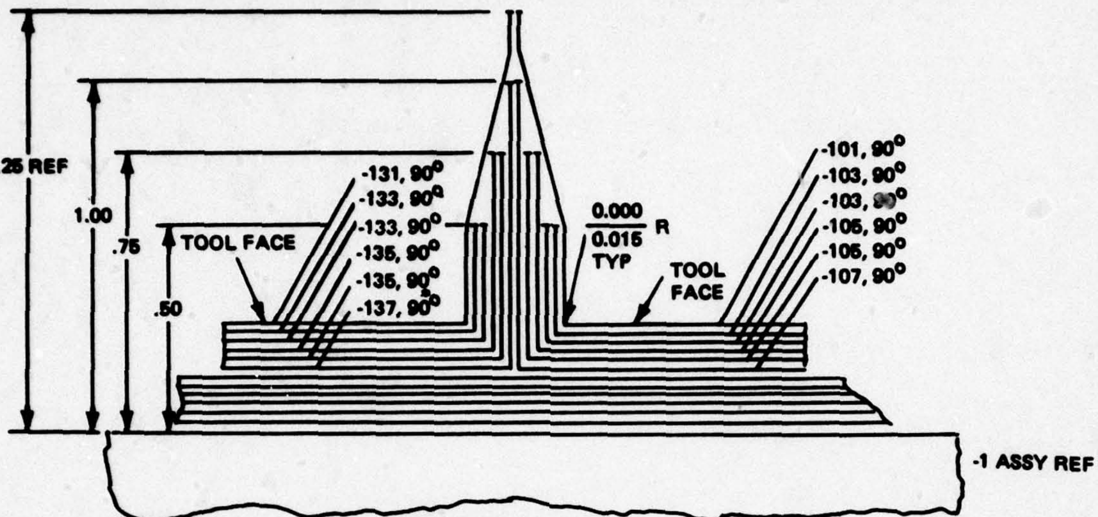
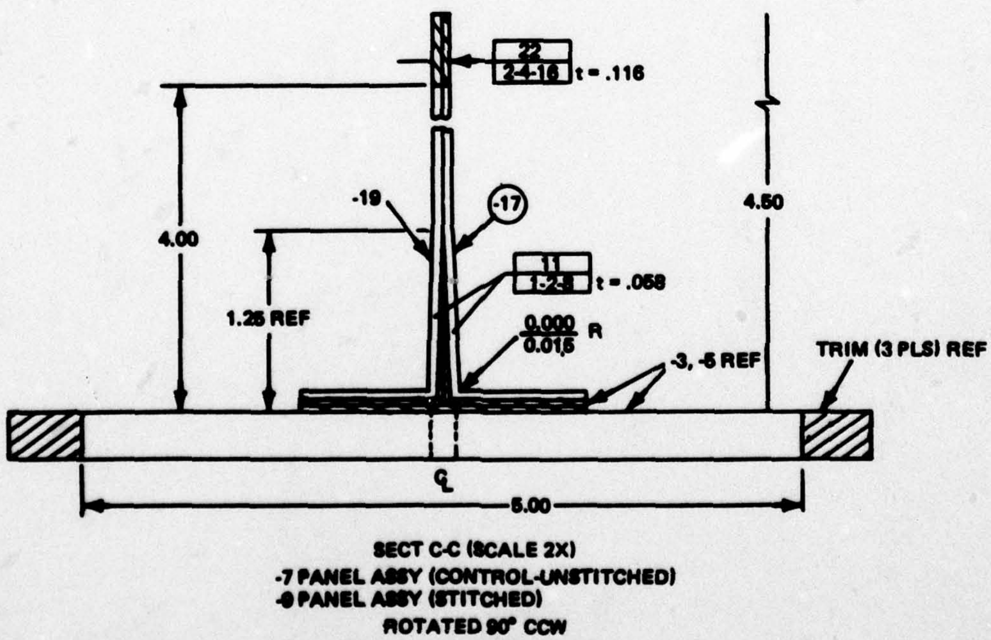


Fig. 15 Concept III (Sheet 1 of 2)



C. Sewn Slug



2921-120W

D. Sewn Slug Concept III

Fig. 15 Concept III (Sheet 2 of 2)

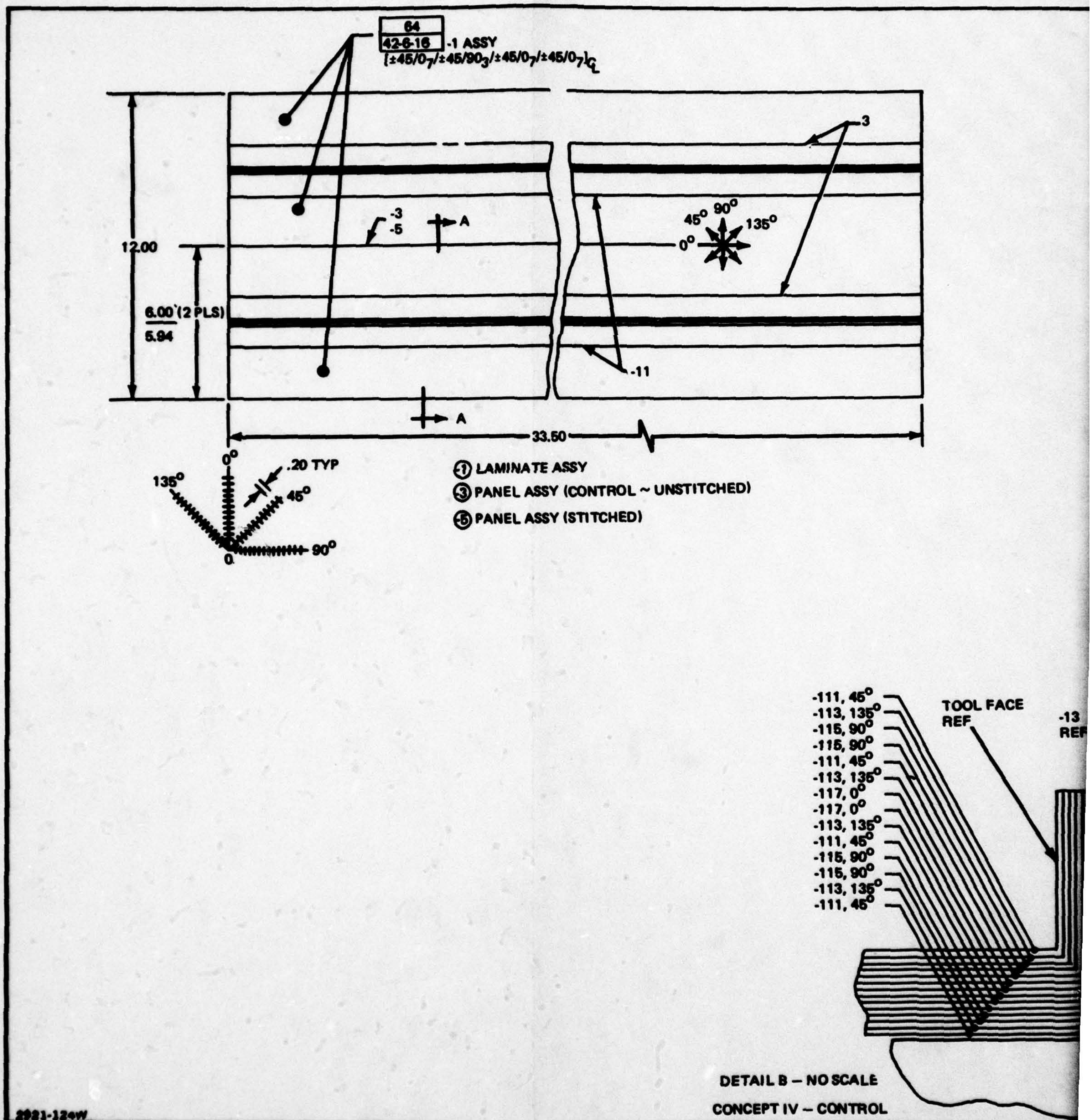
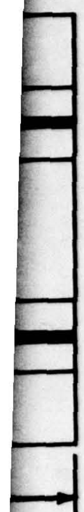
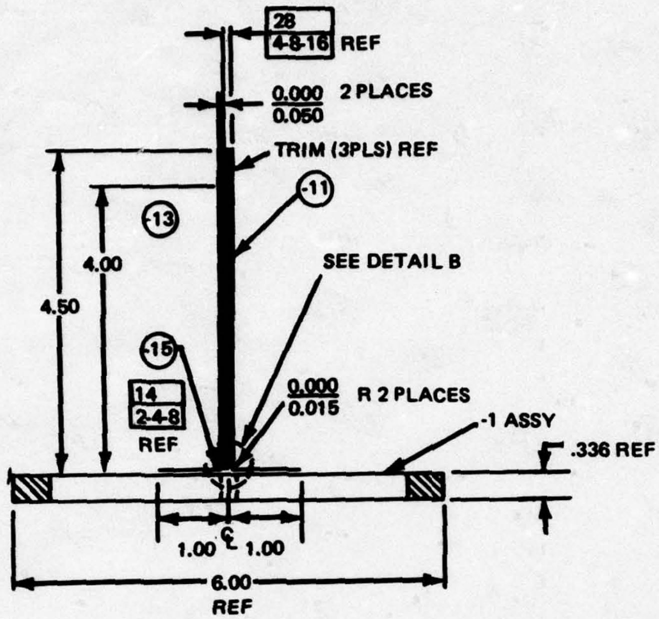
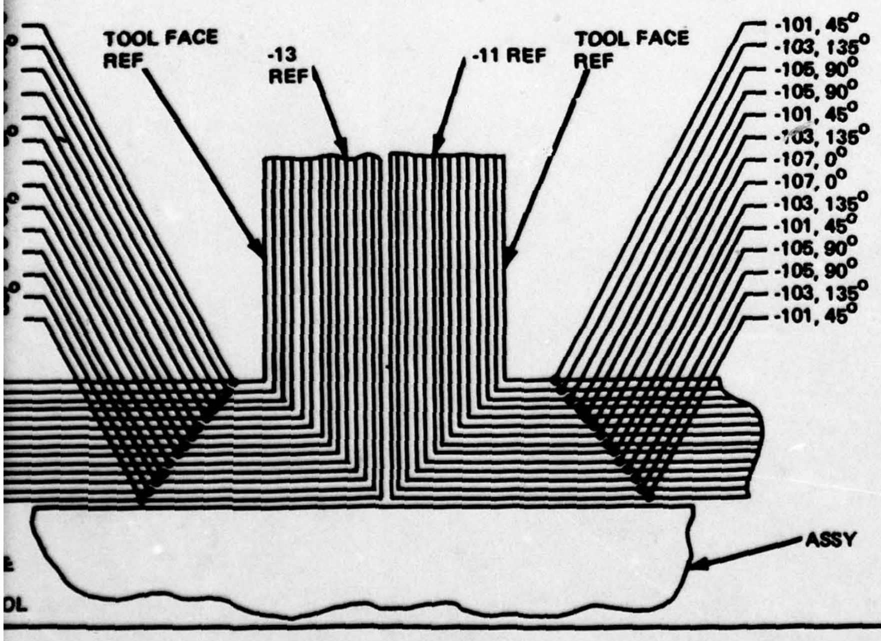


Figure 16 Sewn Spar Concept IV





SECT A-A (ROTATED 90° CCW)
-3 PANEL ASSY (CONTROL)
-5 PANEL ASSY (STITCHED)



- The sewing machine must have clear access on one side and some access on the second side of the material
- The thread should enter from the air passage surface; this places the loops inside and results in a smoother air passage.

The following methods were considered to fulfill these requirements:

- Method I (see Fig. 17)
  - Layup required plies on mold form
  - Transfer compacted uncured laminate from mold form to sewing fixture. Tooling will assure correct positioning and coordination
  - Adjust sewing machine head and thread carrier to predetermined stops
- Method II (see Fig. 18)
  - Layup required plies on mold form
  - Transfer the layup (in this case, a fiberglass reinforced laminate) from the mold form to the sewing fixture, recessed and slotted to accept the material to be sewn. All of the strips are loaded into the recesses of the transfer tool, which has been coordinated to the stitches and provides coordinated pickups for the sewing machine.

In general, the concept of producing a full scale lower wing skin with stitched spar caps is feasible. The complexity is a function of the configuration selected, but all the concepts can be produced by the judicious selection of material, tooling concepts and processes to simplify the manufacturing sequence. A preliminary evaluation of stitching assembly labor costs has been made using the B-1 Composite Horizontal Stabilizer as baseline. As shown in Table 2, the stitched assembly labor costs are reduced by 27%. Stitching data obtained in the coupon and component fabrication phase of the program has shown that the average stitching speed is approximately 1.5 ft/min. A total of twelve panels measuring thirty-three and one-half inches in length were stitched. The combined length of all the stiching performed was 61 ft (coupon fab.) and 11 ft (test box fab.) The test box mechanically attached upper cover and the stitched lower cover are shown in Fig. 19. The test box cover-to-intermediate spars attachment area was used to compare the cost of stitching versus that of mechanical fasteners. The result is shown in Table 3.

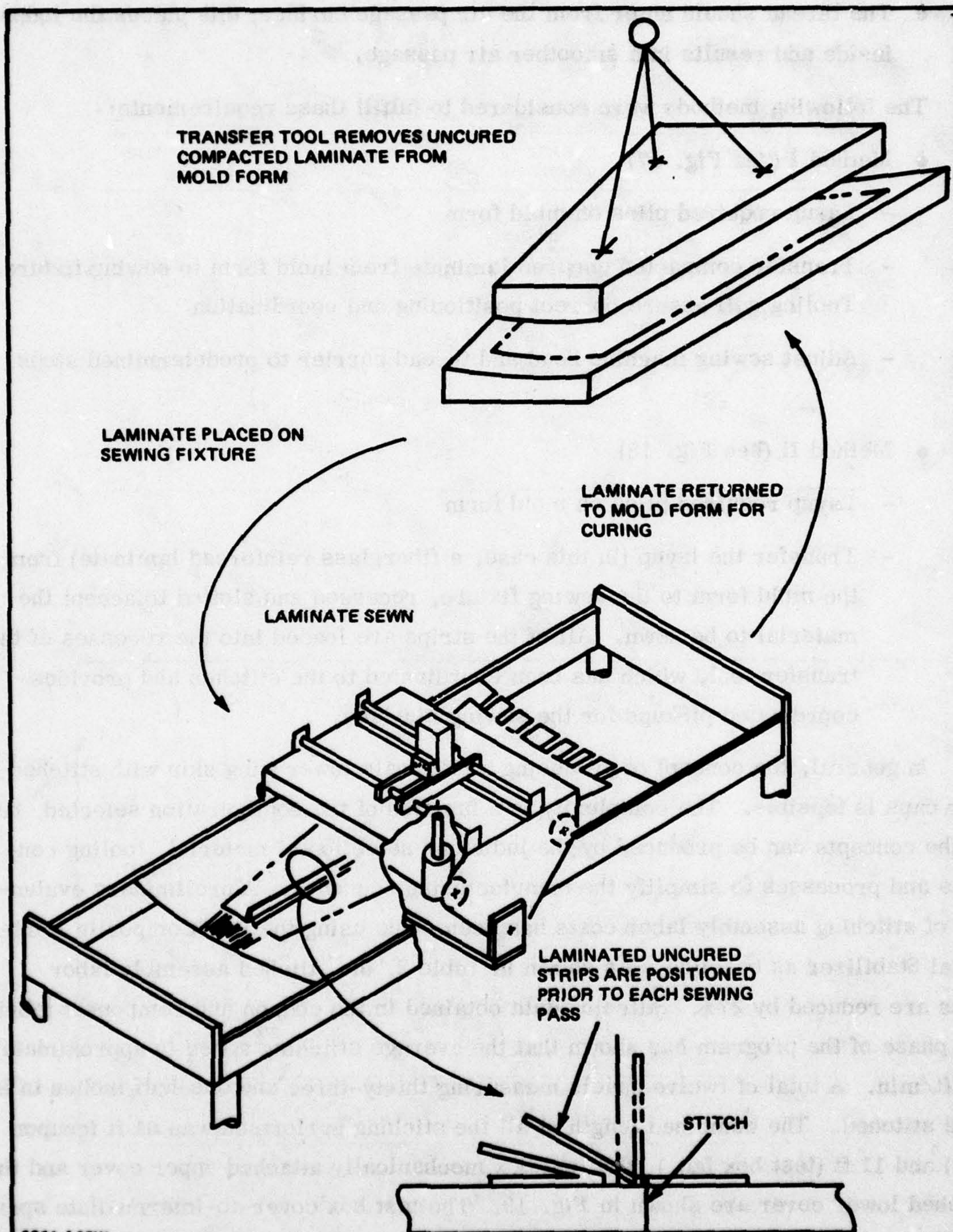


Fig. 17. Automated Tooling Concept.

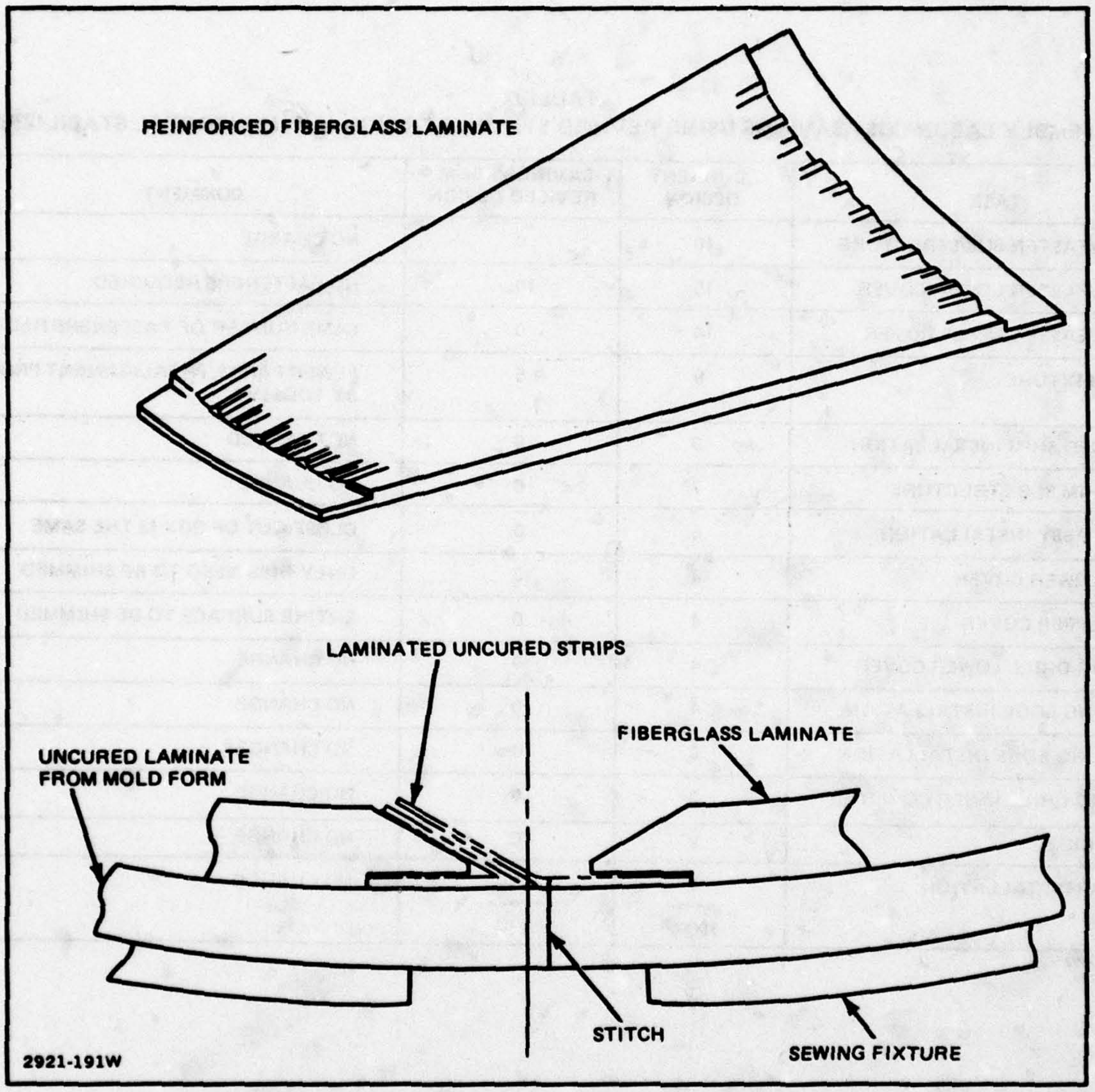
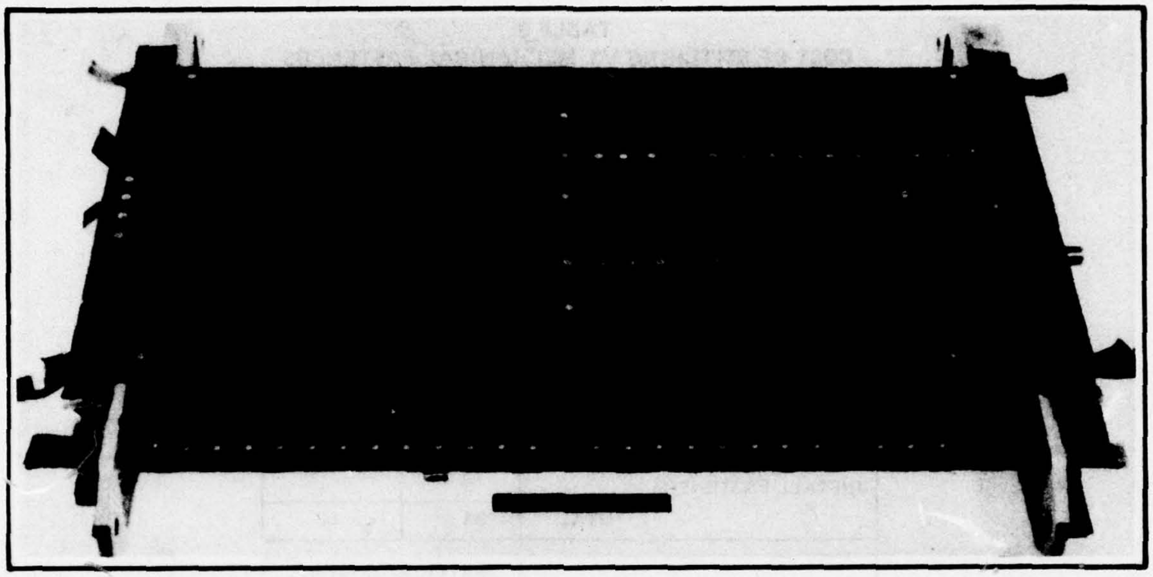


Fig. 18 Fiberglass Sewing Fixture

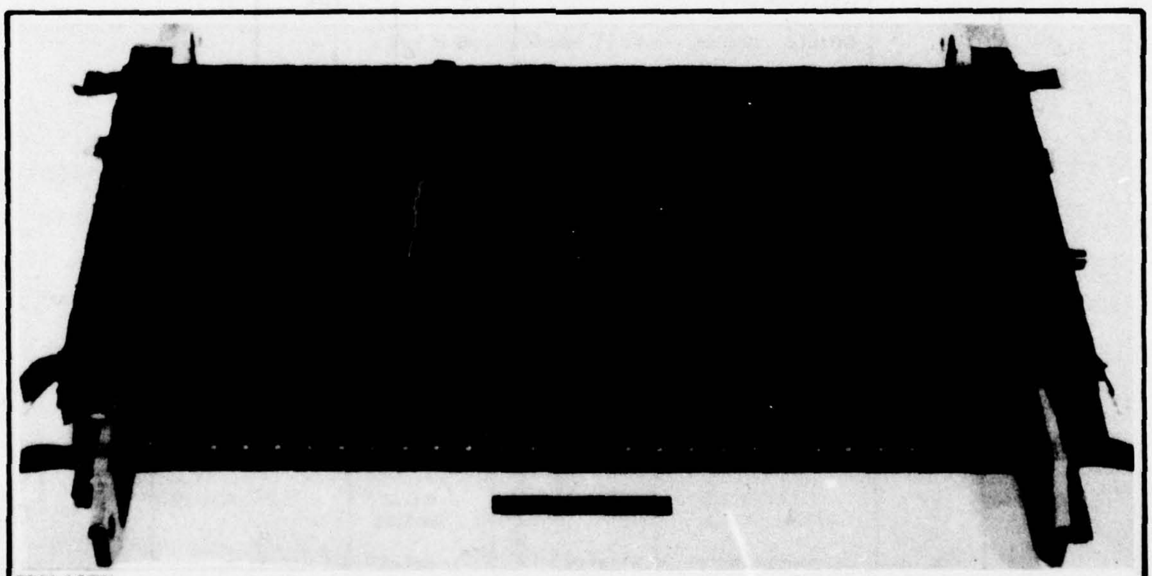
TABLE 2
ASSEMBLY LABOR COST SAVINGS USING REVISED STITCHED DESIGN (B-1 HORIZONTAL STABILIZER)

TASK	CURRENT DESIGN	SAVINGS FROM REVISED DESIGN	COMMENT
DRILL/FASTEN SUB-STRUCTURE	16	0	NO CHANGE
DRILL/FASTEN LOWER COVER	15	10	NO FASTENERS REQUIRED
DRILL/FASTEN UPPER COVER	14	0	SAME NUMBER OF FASTENERS REQUIRED
LOAD FIXTURE	9	5	FEWER PARTS, PREALIGNMENT PROVIDED BY TOOLING
TAPERED SHIM INSTALLATION	9	9	NOT NEEDED
LIQ. SHIM SUB-STRUCTURE	7	0	NO CHANGE
FINAL ASSY INSTALLATION	5	0	CLOSE OUT OF BOX IS THE SAME
SHIM LOWER COVER	4	3	ONLY RIBS NEED TO BE SHIMMED
SHIM UPPER COVER	4	0	ENTIRE SURFACE TO BE SHIMMED
HYBRID DRILL LOWER COVER	4	0	NO CHANGE
LEADING EDGE INSTALLATION	4	0	NO CHANGE
TRAILING EDGE INSTALLATION	3	0	NO CHANGE
HYBRID DRILL UPPER COVER	3	0	NO CHANGE
REWORK	2	0	NO CHANGE
TIP CAP INSTALLATION	1	0	NO CHANGE
	100%	27%	

2921-116W



a) TOP COVER, BOLTED



b) BOTTOM COVER, STITCHED

Fig. 19 Test Box Assembly – Upper & Lower Covers

TABLE 3
COST OF STITCHING VS. MECHANICAL FASTENERS

ASSEMBLY	PERSON/HOURS UPPER	PERSON/HOURS LOWER
COVER LAYUP	48	48
SPAR CAP LAYUP	10	24
PREPARE FOR STITCHING	–	4
STITCH SPAR CAP TO COVER	–	2
PREPARE FOR CURING	–	4
DRILL, REAM AND CSK	24	–
INSPECT HOLES	2	–
INSTALL FASTENERS	2	–
TOTAL	86	82

HARDWARE	MATERIAL COST $ UPPER	MATERIAL COST $ LOWER
THREAD (1)	–	0.60
NEEDLES (2)	–	2.20
DRILLS	5	–
FASTENERS (3)	81	–
TOTAL	86	2.80

2921-194W

(1) KEVLAR (120 LB. BREAKING STRENGTH) AT .005 $/FT.

(2) FOUR STEEL SEWING NEEDLES AT $0.55 EACH.

(3) FIFTY-FOUR RIVNUTS AT $1.50 EACH.

LABOR SAVINGS – (4 HR X 30 $/HR) = $ 120.00

MATERIAL SAVINGS = $ 83.20

TOTAL = $ 203.20

NUMBER OF HOLES = 54

WHICH RESULTS IN A SAVINGS PER ASSEMBLY HOLE OF $3.76.

SECTION III

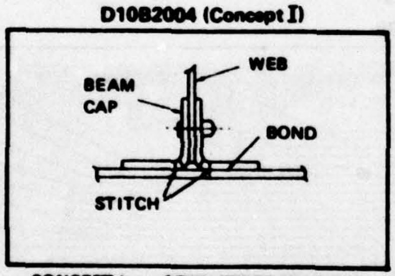
COUPON FABRICATION, TEST AND FAILURE ANALYSIS

3.1 STITCHED SPECIMEN FABRICATION

All of the test element assemblies were laid up using a tape-on mylar system with a 0.20 inch stagger index. The tool material was predominantly aluminum with the only exceptions being the spacer to form Concept I (tool steel) and the punch for the holes in Concept IIA (tool steel).

All assemblies were first sewn and then integrally cured at 85 psi. Following cure and post cure, each assembly was ultrasonically inspected and x-rayed. The test specimens were then cut from the large panels, assembled and tested. A detail fabrication description for each concept follows:

D10B2004 (Concept I)



CONCEPT I – SEWN "TEE" SPAR CAP TO COVER

o D10B2004 (Concept I)

- The preformed angles D10B2004-21 (Fig. 12) were positioned relative to cover panel D10B2004-1 (Fig. 20) on the tool
- The assembly was mechanically aligned on the sewing machine. The vertical legs of the angles were leaned away for clearance when sewing
- The sewn assembly (Fig. 21) was returned to the tool
- The spacer between the angles was positioned
- The side pressure bars, caul plates, dams and bleeder systems were installed

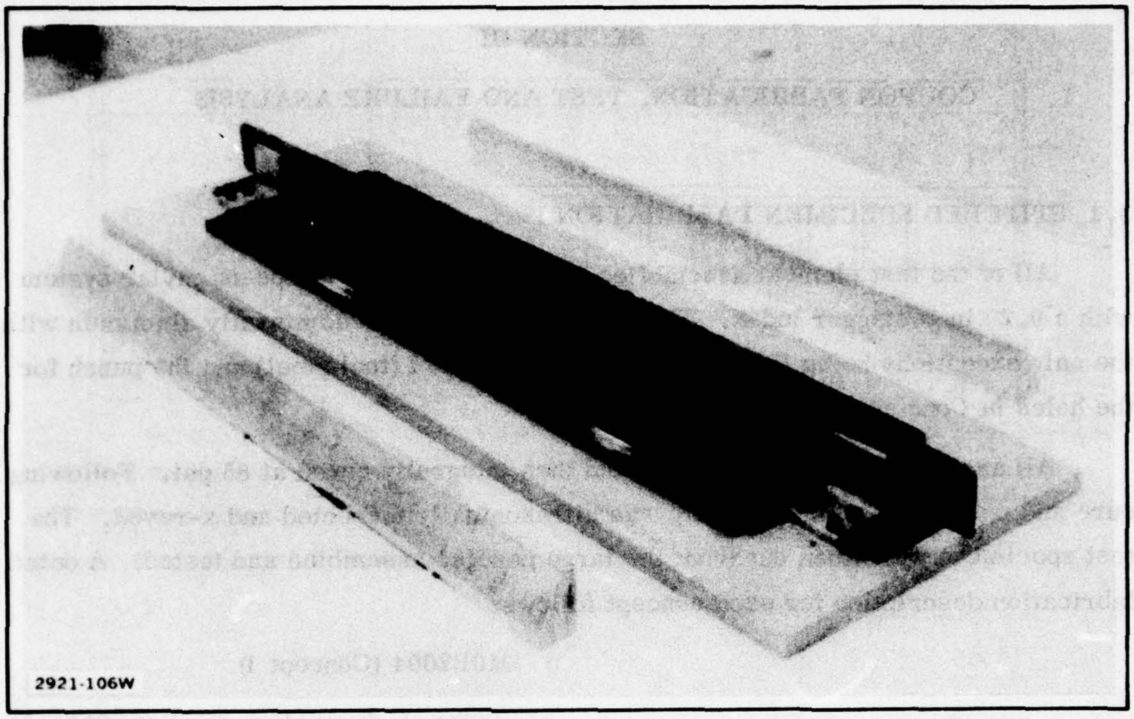


Fig. 20 Cap Positioning

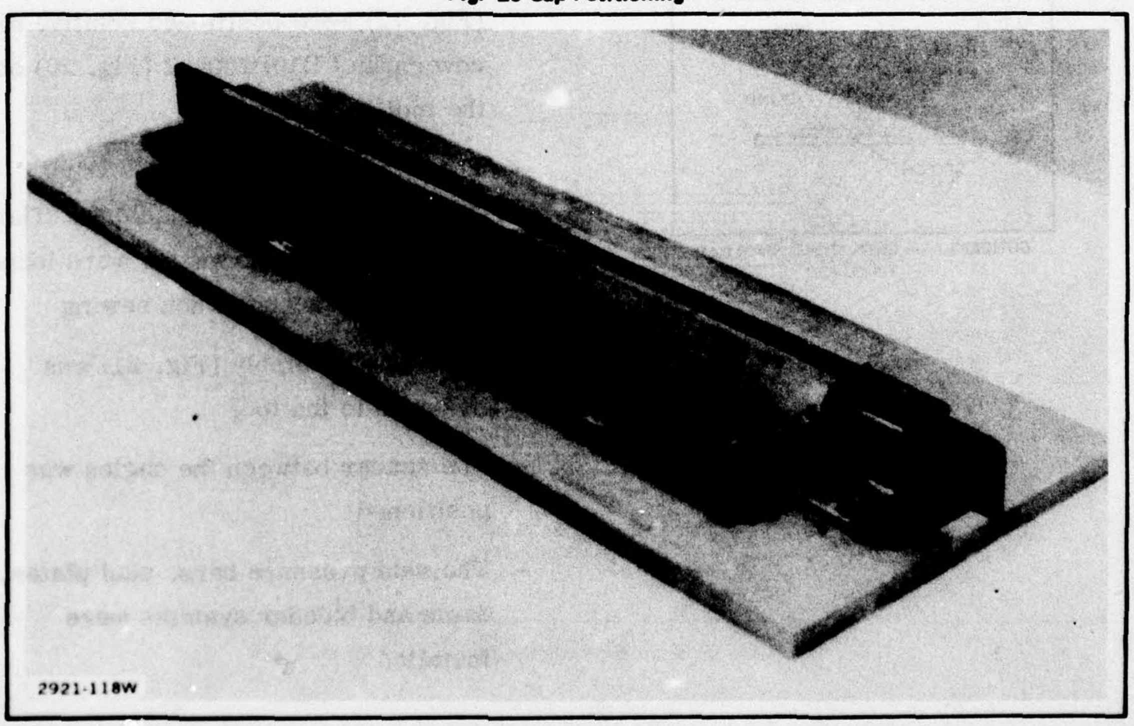
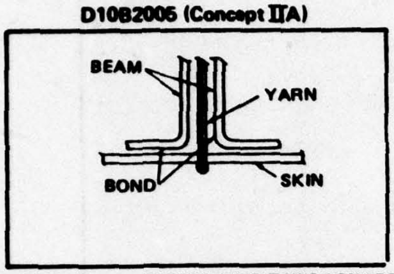


Fig. 21 Sewn Assembly

- The assembly was cured
- The cured part was removed from the tool (Fig. 22). Figure 23 shows a bottom view of the two parallel rows of stitches

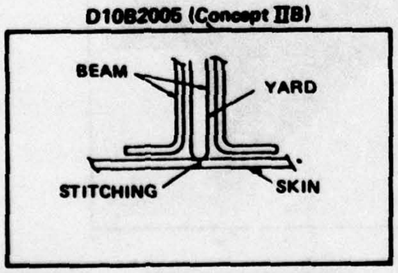
D10B2005 (Concept IIA)



CONCEPT IIa – THRU COVER TOWS BONDED TO SPAR WEB

- D10B2005 (Concept IIA)
  - Tooling was provided to align and space a series of holes along the centerline of cover D10B2005-1 (Fig. 14)
  - A continuous filament 5,000 end strand was drawn through each hole with a long loop on the upper surface
  - This loop was trimmed to create a 10,000 end tow
  - Adhesive rope (EA9601) and film adhesive (Metlbond 329) were applied to the tows, the side angles were positioned, and the assembly was loaded into the tool and cured

D10B2005 (Concept IIB)



CONCEPT IIb – TOWS STITCHED TO THE COVER AND BONDED TO SPAR WEB

- D10B2005 (Concept IIB)
  - Two 0^{o} plies of graphite/epoxy tape were positioned (Fig. 24) perpendicular to -1 centerline
  - A single stitch was made down the centerline
  - The plies were folded about the stitch (Fig. 25) and trimmed to length

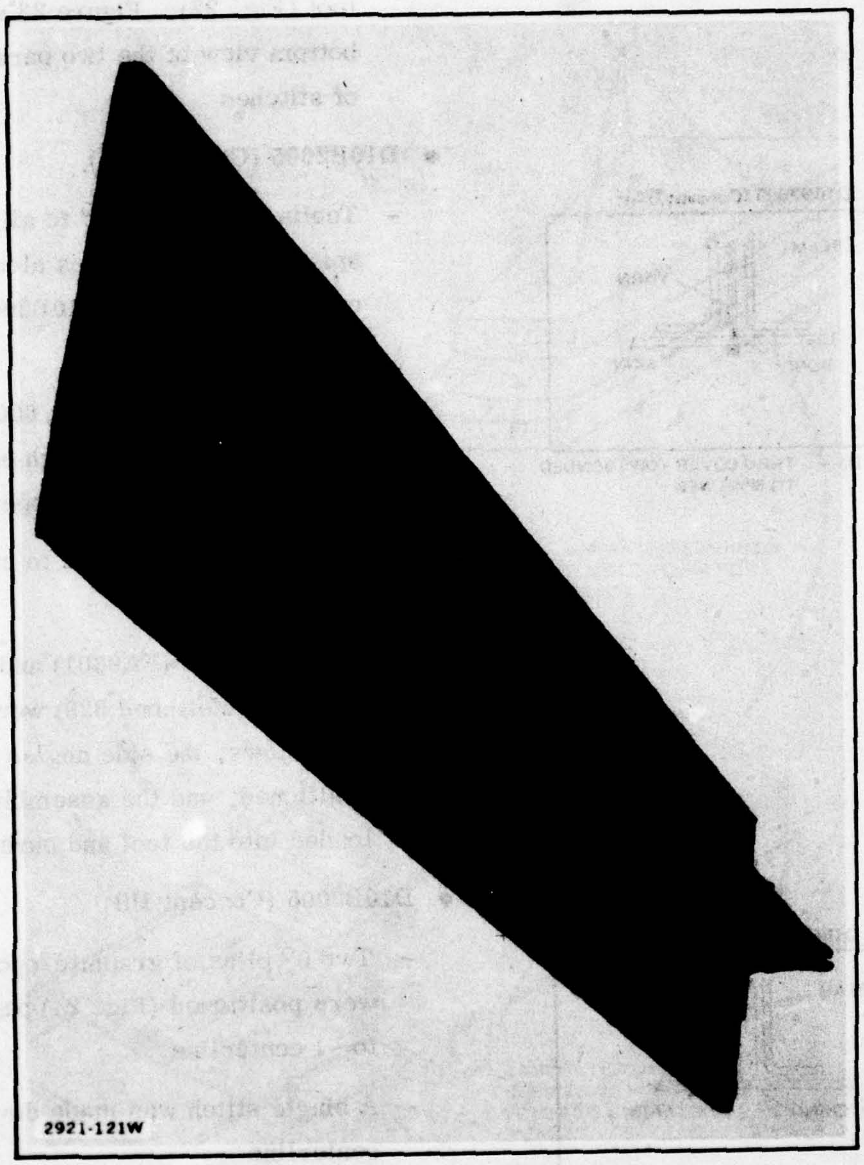


Fig. 22 Cured Assembly

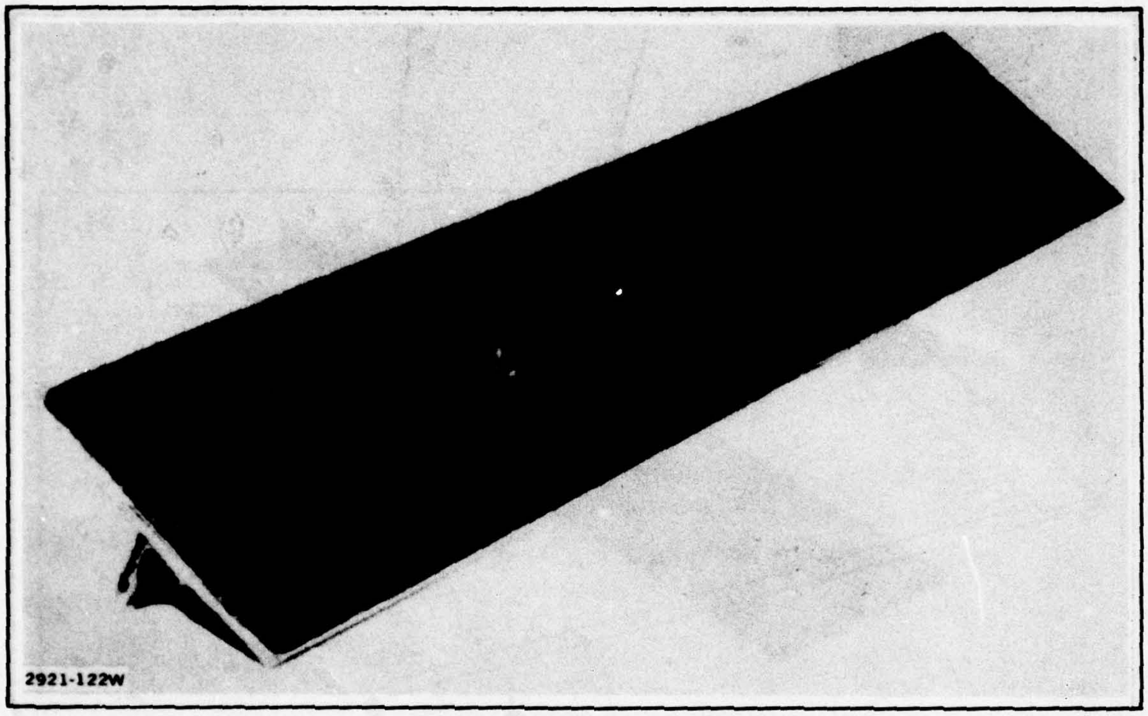


Fig. 23 Stitched Cover

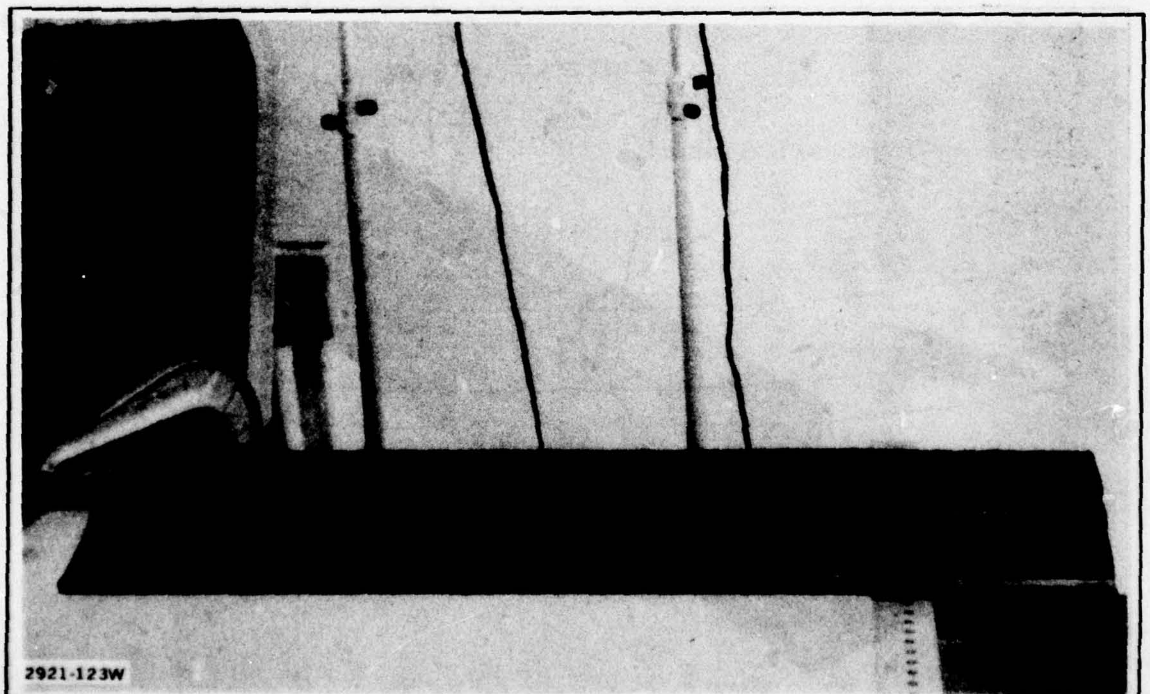


Fig. 24 Concept IIB Stitched Panel

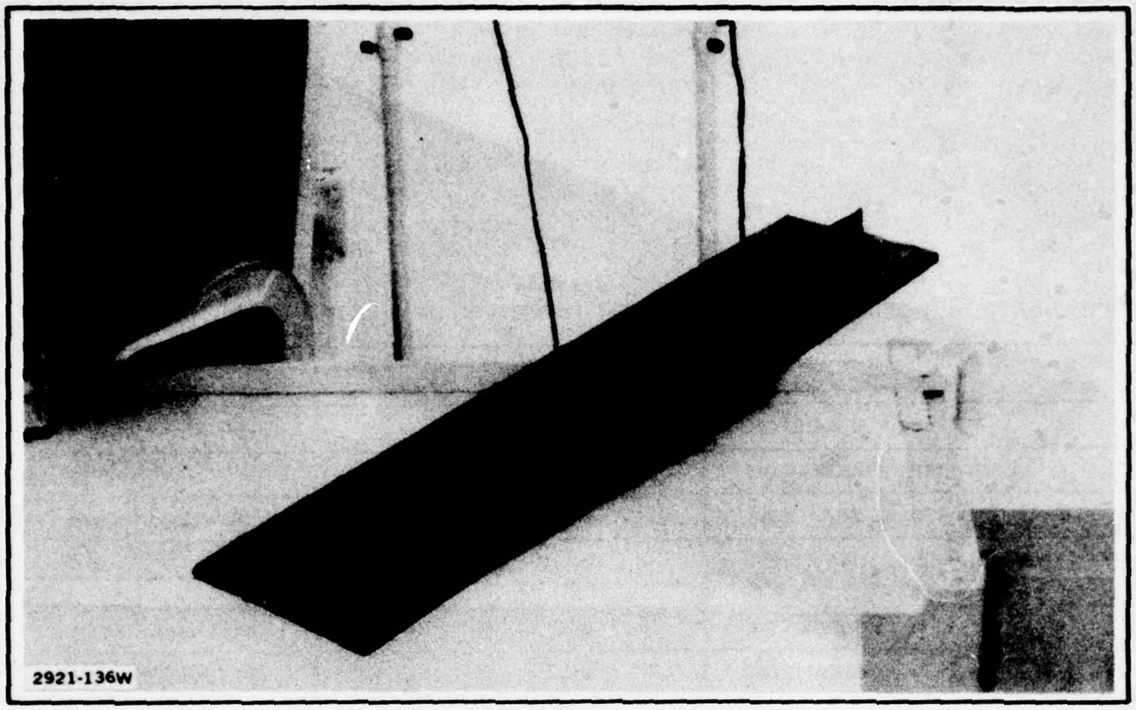


Fig. 25 Concept IIB Folded Graphite/Epoxy Tape

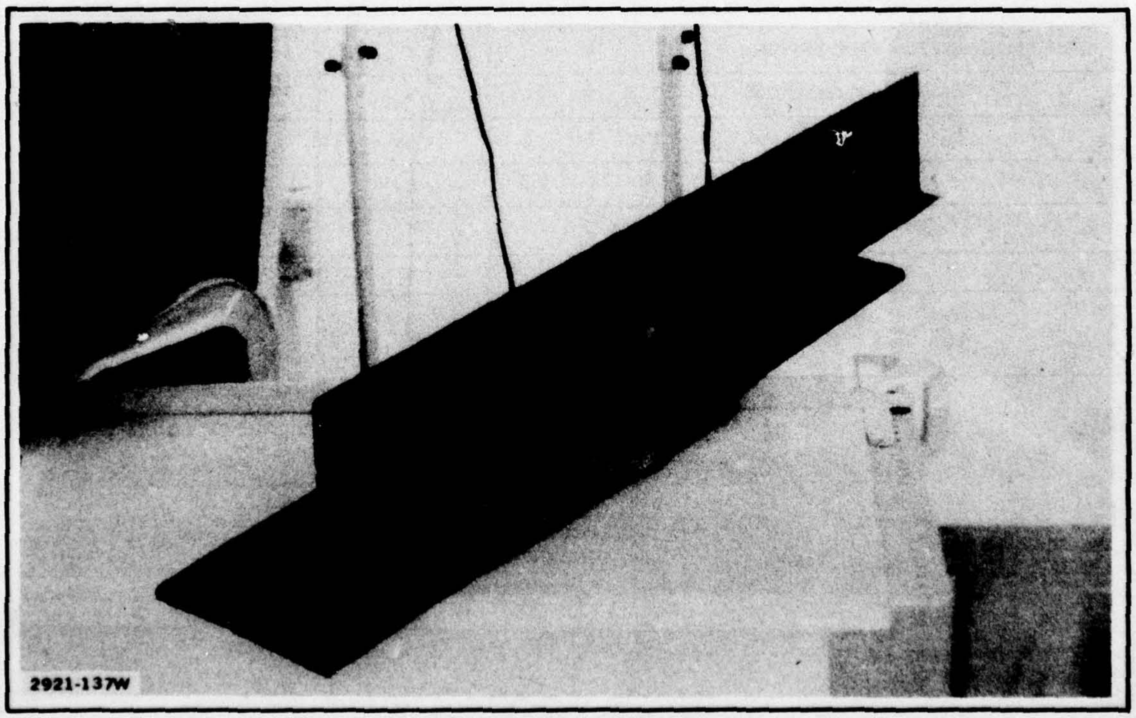
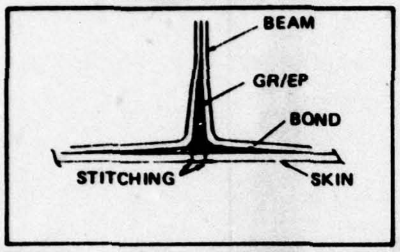


Fig. 26 Concept IIB Angle Positioning

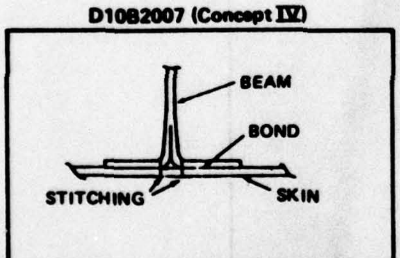
- Adhesive rope was applied (Fig. 26) and preformed angles were positioned, and the assembly was then loaded into the tool and cured.

D10B2006 (Concept III)



CONCEPT III – SEWN SLUG BONDED TO SPAR WEB, CAP AND COVER

D10B2007 (Concept IV)



CONCEPT IV – SPAR SEWN TO COVER AND THRU WEB AT BEAM CAP

- D10B2006 (Concept III)
  - Cap D10B2006-15 (Fig. 15C) was positioned (Fig. 27) on the centerline of cover D10B2006-1 (Fig. 15)
  - Preformed laminates D10B2006-11; -13 (Fig. 15) were positioned on the cover, and the assembly was mechanically positioned on the sewing machine. The slugs were leaned away for clearance when sewing (Fig. 28). Figure 29 shows the parallel lines of stitches that fasten slugs D10B2006-11; -13 and -15 (Fig. 15B) to the cover
  - The stitched assembly was then loaded into the tool and cured.
- D10B2007 (Concept IV)
  - The angles D10B2007-11; -13 (Fig. 16) were positioned on the D10B2007-1 cover, leaned away for sewing clearance, sewn, loaded into the tool, and cured.

3.2 MOISTURE-CONDITIONING ANALYSIS

An analysis was performed to determine an appropriate moisture-conditioning sequence for the test specimens prior to strength testing. A twenty year actual service life and the climatic condition at Andersen AFB in Guam were assumed. (Andersen was identified as the worst-case bomber base in the Environmental

Fig. 27 Concept III Cap Positioning

Fig. 28 Concept III Sewn Slug

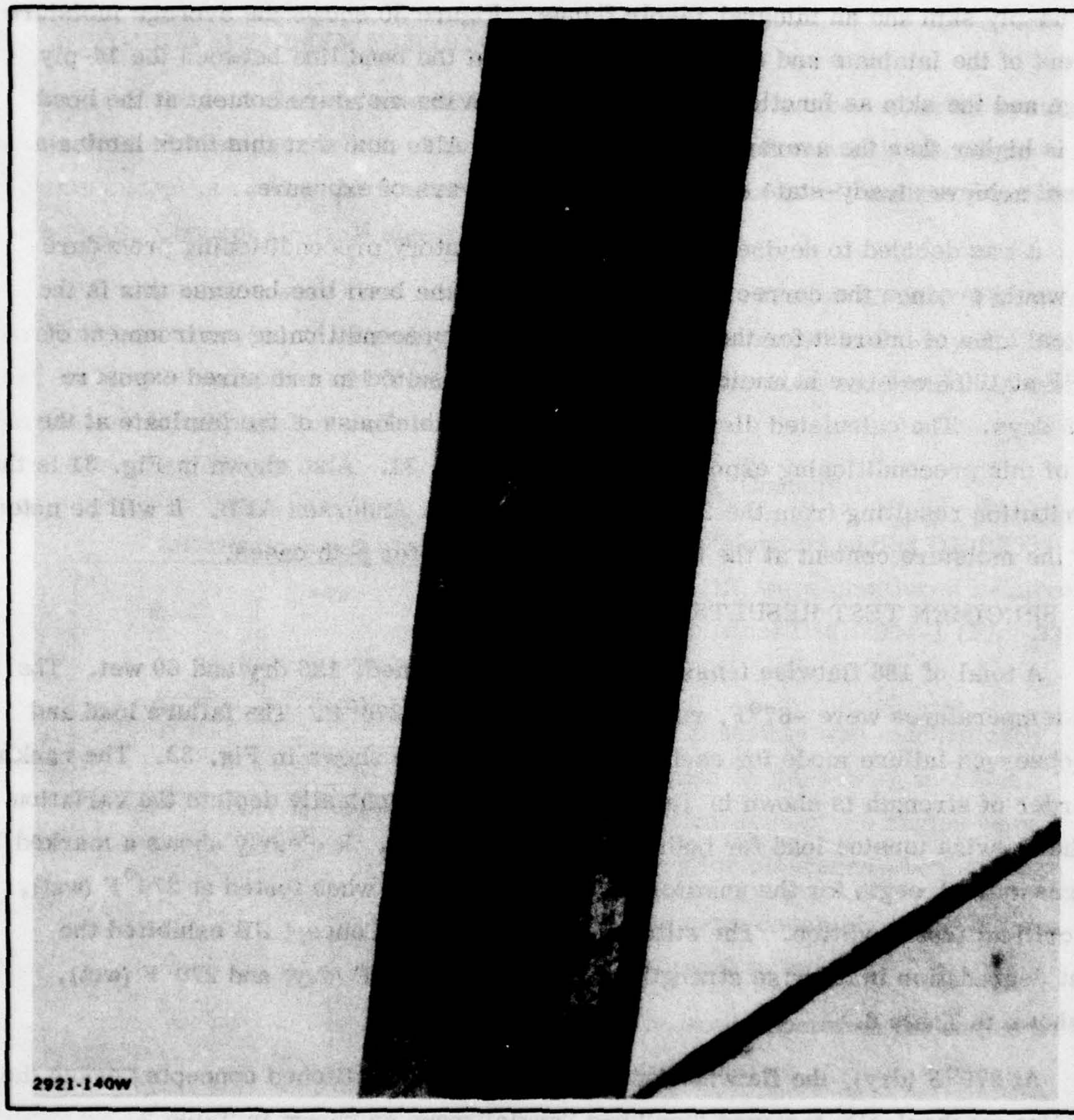


Fig. 29 Concept III Completed Sewn Slug

Sensitivity Program, AF contract F-33615-75-C-5324). The operational scenario assumed one 10.5 hour B-1 bomber composite standard mission every seventh day. This mission profile is shown in Table 4.

The moisture-distribution history for the service life described above was analytically determined for a 78-ply laminate. This represents the combined thickness of a 64-ply skin and an integral 14-ply flange. Figure 30 shows the average moisture content of the laminate and the moisture content at the bond line between the 14-ply flange and the skin as functions of time. Note that the moisture content at the bond line is higher than the average moisture content. Also note that this thick laminate did not achieve steady-state conditions in the 20 years of exposure.

It was decided to devise an accelerated laboratory preconditioning procedure that would produce the correct moisture content at the bond line because this is the critical area of interest for the test specimens. A preconditioning environment of 180°F at 100% relative humidity was chosen; this resulted in a required exposure of 65 days. The calculated distribution through the thickness of the laminate at the end of this preconditioning exposure is shown in Fig. 31. Also shown in Fig. 31 is the distribution resulting from the 20-year service life at Andersen AFB. It will be noted that the moisture content at the bond line is the same for both cases.

3.3 SPECIMEN TEST RESULTS

A total of 186 flatwise tension tests were performed, 126 dry and 60 wet. The test temperatures were -67°F, room temperature and 270°F. The failure load and the observed failure mode for each specimen tested are shown in Fig. 32. The ranking, in order of strength is shown in Table 5. Figure 33 graphically depicts the variation of the flatwise tension load for both dry and wet coupons. It clearly shows a marked decrease in strength for the unstitched (control) coupons when tested at 270°F (wet), the critical test condition. The stitched Concept III and Concept IIB exhibited the least degradation in flatwise strength when tested at 270°F (dry) and 270°F (wet), as shown in Table 6.

At 270°F (dry), the flatwise tension strength of the stitched concepts versus the baseline mechanically fastened "tee" and "angle" were as shown in Table 7.

TABLE 4
STANDARD B-1 MISSION PROFILE

ELAPSED TIME SEGMENTS (HR)	MISSION SEGMENTS	SKIN TEMP (^oF)
0.0 – 0.05	TAKEOFF	68
0.05 – 0.517	SUBSONIC CLIMB TO 25,000 FT	
0.517– 6.82	SUBSONIC CRUISE AT 25,000 FT, M = 0.70	23
6.82 – 6.98	SUPERSONIC CLIMB TO 55,000 FT	
6.98 – 7.17	SUPERSONIC CRUISE AT 55,000 FT, M = 2.10	260
7.17 – 7.33	SUPERSONIC DESCENT TO 25,000 FT	
7.33 – 7.70	REFUEL AT 25,000 FT, M = 0.7	23
7.70 – 8.17	SUBSONIC DESCENT TO SEA LEVEL	
8.17 – 9.30	TERRAIN FOLLOW AT SEA LEVEL, M = 0.85	134
9.32 – 9.55	TERRAIN FOLLOW AT SEA LEVEL, M = 0.95	150
9.57 – 9.67	TERRAIN FOLLOW AT SEA LEVEL, M = 0.55	95
9.67 – 10.00	SUBSONIC CLIMB TO 25,000 FT	
10.00 – 10.40	SUBSONIC CRUISE AT 25,000 FT, M = 0.70	23
10.40 – 10.50	LANDING	68

2921-141W

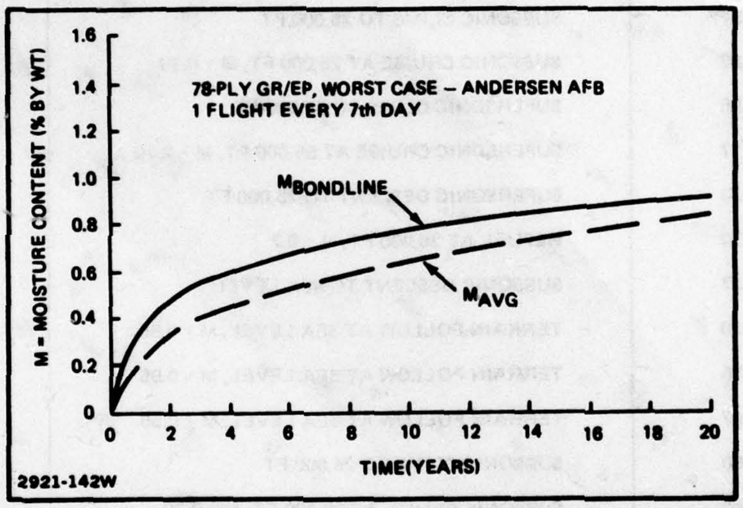


Fig. 30 Moisture Content Versus Time

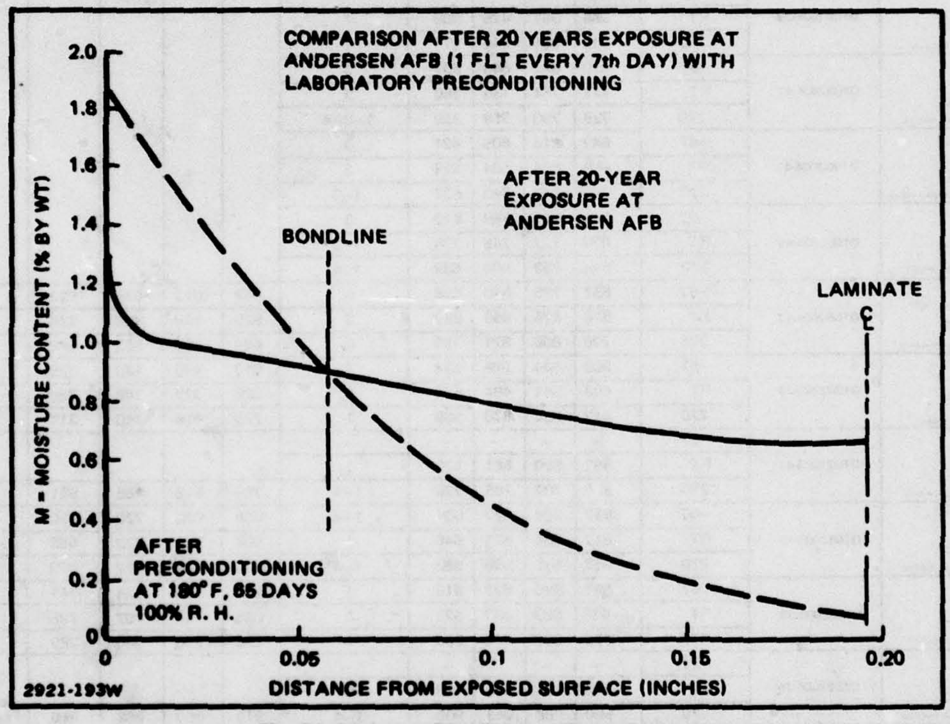


Fig. 31 Moisture Distribution Through Laminate

CONFIGURATION	PART NO.	TEST TEMP °F	DRY FAIL LOAD LB/IN COUPON NO. 1	2	3	DRY AVE LB/IN	DRY OBSERVED FAILURE MODE*	WET FAIL LOAD LB/IN COUPON NO. 1	2	3	WET AVE LB/IN	WET OBSERVED FAILURE MODE*
TEE CAP - MECH ATTACHED	D10B2003-1, -3, -5	−67	905	913	901	906	3					
		RT	908	988	1056	1008	3					
		270	829	794	829	817	2–5					
ANGLE CAP MECH ATTACHED	D10B2003-7, -9, -11	−67	659	643	635	646	2					
		RT	631	683	675	663	2					
		270	548	536	556	546	2					
CONCEPT I CONTROL NOT STITCHED	D10B2004-39	−67	430	496	404	443	1					
		RT	386	351	429	389	1					
		270	240	231	342	271	1					
CONCEPT I STITCHED KEVLAR THREAD	D10B2004-43	−67	610	662	640	637	3					
		RT	777	784	736	766	3					
		270	728	790	759	759	1–3–4					
CONCEPT I STITCHED POLYESTER THREAD	D10B2004-47	−67	642	616	605	621	3					
		RT	686	606	594	629	3					
		270	720	672	640	677	1–3					
CONCEPT I STITCHED NYLON THREAD	D10B2004-49	−67	594	647	589	610	3					
		RT	629	727	748	735	1–3					
		270	643	553	609	602	1–4					
CONCEPT I STITCHED KEVLAR THREAD	D10B2004-57	−67	837	798	850	828	3	952	1072	1016	1013	3–6
		RT	816	925	866	869	3	920	948	916	928	6
		270	726	809	821	785	3	684	698	652	678	3–6, 1–6
CONCEPT II CONTROL NOT STITCHED	D10B2006-39	−67	609	544	598	584	1	618	490	480	529	1
		RT	603	541	494	546	1	820	772	748	780	1
		270	442	554	530	509	1	256	416	260	311	1
CONCEPT IIA THROUGH THE COVER TOW	D10B2006-41	−67	–	–	–	–	–					
		RT	652	520	561	578	1					
		270	686	707	785	726	1–4	786	518	468	591	1–4
CONCEPT IIB STITCHED KEVLAR THREAD	D10B2006-43	−67	657	584	572	604	1–4	658	692	720	690	1–4, 5–7
		RT	617	686	635	646	1	588	604	572	588	1–4
		270	552	598	598	583	1–4	632	474	512	539	1–4
CONCEPT III CONTROL NOT STITCHED	D10B2008-23	−67	591	626	627	615	1	692	708	824	741	1
		RT	635	600	633	623	1	688	734	752	725	1
		270	532	502	476	503	1	232	276	360	289	1
CONCEPT III STITCHED KEVLAR THREAD	D10B2008-25	−67	–	–	–	–	–					
		RT	936	1151	996	1028	3					
		270	960	968	1061	996	1–4	940	850	968	919	1–4
CONCEPT IV CONTROL NOT STITCHED	D10B2007-17	−67	630	610	610	617	1	556	552	636	581	1.
		RT	692	564	672	643	1	606	585	574	588	1
		270	368	387	420	392	1	176	176	190	181	1
CONCEPT IV STITCHED KEVLAR THREAD	D10B2007-19	−67	580	704	584	623	1–5	666	720	736	707	1–4, 5–7
		RT	696	684	696	725	1–5	876	956	920	917	1–4, 6
		270	848	794	816	819	1–5	686	757	634	675	1–4, 5

1300-202

*FAILURE MODES

1. FAILURE OF SKIN TO FLANGE BOND
2. DELAMINATION IN BEND OF FLANGE
3. INTERLAMINAR SHEAR FAILURE IN SKIN AT TOE OF FLANGE
4. FAILURE OF STITCH
5. SPLITTING BETWEEN BACK-TO-BACK FLANGES
6. INTERLAMINAR SPLITTING OF THE SKIN
7. FLEX-FAILURE OF SKIN

Fig. 32 CTSA Program – Static Flatwise Tension Test Results

TABLE 5
CTSA PROGRAM – RANK ORDER OF STATIC FLATWISE TENSION STRENGTH TEST RESULTS

SPECIMEN				AVERAGE FAILING LOAD (LB/IN) **
			–67° F TEST (DRY)	
1.	TEE CAP	– MECH ATTACHED	(D108 2003–1)	906
2.	CONCEPT I	– KEVLAR* THREAD	(D108 2004–57)	828
3.	ANGLE CAP	– MECH ATTACHED THREAD	(D108 2003–7)	646
4.	CONCEPT I	– KEVLAR THREAD	(D108 2004–43)	637
5.	CONCEPT IV	– KEVLAR THREAD	(D108 2007–19)	623
6.	CONCEPT I	– POLYESTER THREAD	(D108 2004–47)	621
7.	CONCEPT IV	– CONTROL	(D108 2007–17)	617
8.	CONCEPT III	– CONTROL	(D108 2008–23)	615
9.	CONCEPT I	– NYLON THREAD	(D108 2004–49)	610
10.	CONCEPT IIB	– STITCHED (KEVLAR)	(D108 2005–43)	604
11.	CONCEPT II	– CONTROL	(D108 2005–39)	584
12.	CONCEPT I	– CONTROL	(D108 2004–39)	443
			ROOM TEMPERATURE TEST (DRY)	
1.	CONCEPT III	– KEVLAR THREAD	(D108 2008–25)	1028
2.	TEE CAP	– MECH ATTACHED	(D108 2003–3)	1008
3.	CONCEPT I	– KEVLAR* THREAD	(D108 2004–57)	889
4.	CONCEPT I	– KEVLAR THREAD	(D108 2004–43)	766
5.	CONCEPT I	– NYLON THREAD	(D108 2004–49)	735
6.	CONCEPT IV	– KEVLAR THREAD	(D108 2008–19)	725
7.	ANGLE CAP	– MECH ATTACHED	(D108 2003–9)	663
8.	CONCEPT IIB	– STITCHED	(D108 2005–43)	646
9.	CONCEPT IV	– CONTROL	(D108 2008–17)	643
10.	CONCEPT I	– POLYESTER THREAD	(D108 2004–47)	629
11.	CONCEPT III	– CONTROL	(D108 2008–23)	623
12.	CONCEPT IIA	– TOWS	(D108 2005–41)	573
13.	CONCEPT II	– CONTROL	(D108 2005–39)	546
14.	CONCEPT I	– CONTROL	(D108 2004–39)	389
			+270° F TEST (DRY)	
1.	CONCEPT III	– KEVLAR THREAD	(D108 2008–25)	986
2.	CONCEPT IV	– KEVLAR THREAD	(D108 2007–19)	820
3.	TEE CAP	– MECH ATTACHED	(D108 2003–5)	817
4.	CONCEPT I	– KEVLAR* THREAD	(D108 2004–57)	785
5.	CONCEPT I	– KEVLAR THREAD	(D108 2004–43)	759
6.	CONCEPT IIA	– TOWS	(D108 2005–41)	726
7.	CONCEPT I	– POLYESTER THREAD	(D108 2004–47)	677
8.	CONCEPT I	– NYLON THREAD	(D108 2004–49)	602
9.	CONCEPT IIB	– STITCHED	(D108 2005–43)	583
10.	ANGLE CAP	– MECH ATTACHED	(D108 2003–11)	546
11.	CONCEPT II	– CONTROL	(D108 2005–39)	509
12.	CONCEPT III	– CONTROL	(D108 2008–23)	503
13.	CONCEPT IV	– CONTROL	(D108 2007–17)	392
14.	CONCEPT I	– CONTROL	(D108 2004–39)	271

				AVERAGE FAILING LOAD (LB/IN) **
			–67° F TEST (WET)	
1.	CONCEPT I	– KEVLAR THREAD	(D108 2004–57)	1013
2.	CONCEPT III	– CONTROL	(D108 2008–23)	741
3.	CONCEPT IV	– KEVLAR THREAD	(D108 2007–19)	707
4.	CONCEPT IIB	– STITCHED (KEVLAR)	(D108 2005–43)	690
5.	CONCEPT IV	– CONTROL	(D108 2007–17)	561
6.	CONCEPT II	– CONTROL	(D108 2015–39)	529
			ROOM TEMPERATURE TEST (WET)	
1.	CONCEPT I	– KEVLAR THREAD	(D108 2004–57)	928
2.	CONCEPT IV	– KEVLAR THREAD	(D108 2007–19)	917
3.	CONCEPT II	– CONTROL	(D108 2005–39)	780
4.	CONCEPT III	– CONTROL	(D108 2008–23)	725
5.	CONCEPT IV	– CONTROL	(D108 2007–17)	588
6.	CONCEPT IIB	– STITCHED (KEVLAR)	(D108 2005–43)	568
			+270° F TEST (WET)	
1.	CONCEPT III	– KEVLAR THREAD	(D108 2008–25)	919
2.	CONCEPT I	– KEVLAR THREAD	(D108 2004–57)	678
3.	CONCEPT IV	– KEVLAR THREAD	(D108 2007–19)	675
4.	CONCEPT IIA	– TOWS (GRAPHITE)	(D108 2005–41)	591
5.	CONCEPT IIB	– STITCHED (KEVLAR)	(D108 2005–43)	530
6.	CONCEPT II	– CONTROL	(D108 2005–39)	311
7.	CONCEPT III	– CONTROL	(D108 2008–23)	289
8.	CONCEPT IV	– CONTROL	(D108 2007–17)	181

* 26 PLIES CAP
** AVERAGE OF 3 TESTS

2921-133W

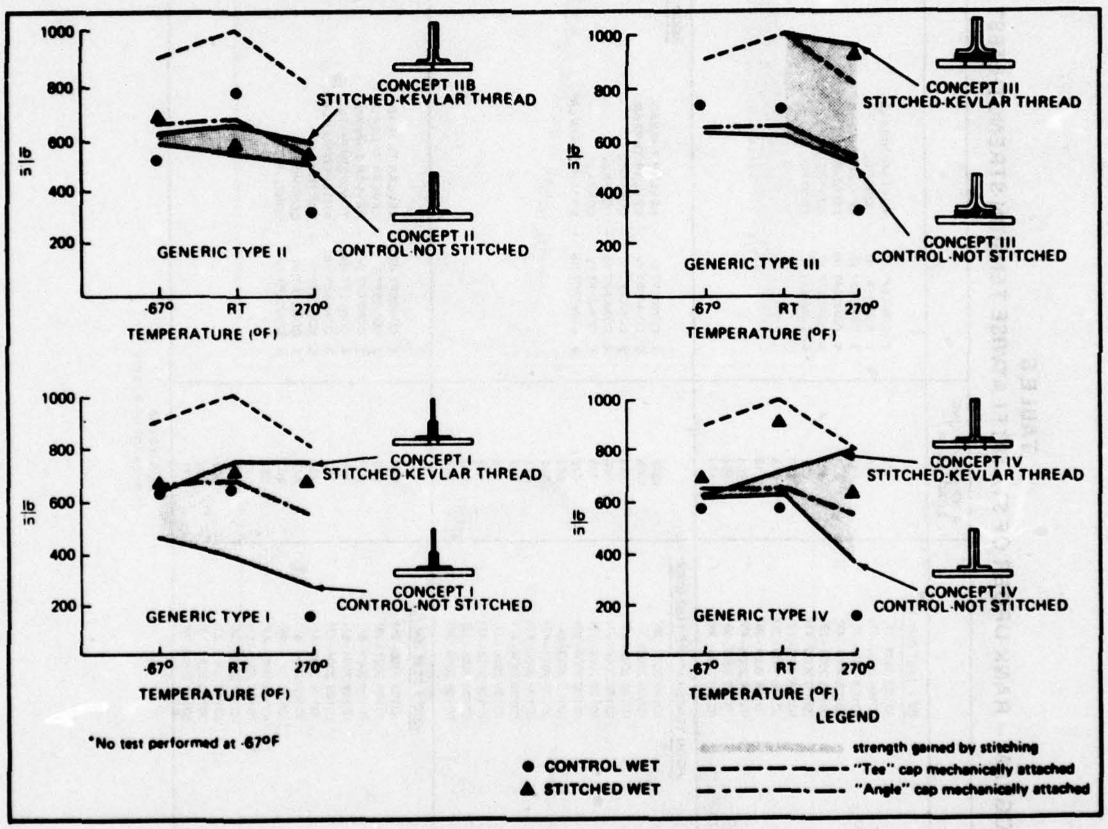


Fig. 33 CTSA - Program Test Results

TABLE 6
RANKING IN ORDER OF STRENGTH

CONCEPT	270°F (DRY) FAILURE LOAD*	270°F (WET) FAILURE LOAD*	% REDUCTION
CONCEPT III (STITCHED)	996 LB/IN.	919 LB/IN.	8
CONCEPT IIB (STITCHED)	583 LB/IN.	539 LB/IN.	8
CONCEPT I (STICHED)	785 LB/IN.	678 LB/IN.	14
CONCEPT IV (STITCHED)	820 LB/IN.	675 LB/IN.	18
CONCEPT IIA (TOWS)	726 LB/IN.	591 LB/IN.	19
CONCEPT II (CONTROL UNSTITCHED)	509 LB/IN.	311 LB/IN.	39
CONCEPT III (CONTROL UNSTITCHED)	503 LB/IN.	289 LB/IN.	43
CONCEPT IV (CONTROL UNSTITCHED)	392 LB/IN.	181 LB/IN.	54

* AVERAGE OF THREE TESTS

2921-195W

TABLE 7
FLATWISE TENSION STRENGTH OF INTEGRALLY CURED SPECIMENS VS MECHANICAL BASELINES

	STRENGTH RATIO		WT.
	"TEE"	"ANGLE"	(LB/FT)
CONCEPT III (KEVLAR THREAD)	1.22	1.82	1589
CONCEPT IV (KEVLAR THREAD)	1.00	1.50	1.642
CONCEPT I (KEVLAR THREAD)	0.96	1.44	1.982
CONCEPT IIA (TOWS)	0.89	1.33	1.640
CONCEPT I (POLYESTER THREAD)	0.83	1.24	1.925
CONCEPT I (NYLON)	0.74	1.10	1.925
CONCEPT IIB .(KEVLAR THREAD)	0.71	1.07	1.635
CONCEPT II (CONTROL UNSTITCHED)	0.62	0.93	1.636
CONCEPT III (CONTROL UNSTITCHED)	0.62	0.93	1.589
CONCEPT IV (CONTROL UNSTITCHED)	0.48	0.72	1.642
CONCEPT I (CONTROL UNSTITCHED)	0.33	0.50	1.786

** USING THE MECHANICALLY ATTACHED "TEE" CAP (817 LB/IN.) AND "ANGLE" CAP (546 LB/IN.) AS BASELINE

2921-196W

The best concept based on its strength* to weight ratio was Concept III (Kevlar Thread) with a flatwise tension strength to weight ratio of 578. The rest were as follows:

Concept IV (KEVLAR THREAD)	411
Concept IIA (TOWS)	360
Concept I (KEVLAR THREAD)	342
Concept IIB (KEVLAR THREAD)	329
Concept II (CONTROL UNSTITCHED)	190
Concept III (CONTROL UNSTITCHED)	182
Concept IV (CONTROL UNSTITCHED)	101

The selection of the subcomponent configuration was based on the preceeding element test results and present stitching capabilities. The best structural concept was Concept III (Kevlar Thread), which rated first in strength, consistency and weight. Unfortunately, it had to be eliminated because present stitching capabilities make its manufacturing costs prohibitive. Likewise, for the second best, Concept IV (Kevlar Thread). The third best was Concept I (Kevlar Thread). This was the selected configuration for the subcomponent test. Concept I (Kevlar Thread) is compatible with present stitching technology. The selected configuration compares favorably with the mechanically attached baselines as shown below:

		MECHANICALLY ATTACHED	
	CONCEPT I	"TEE"	"ANGLE"
Strength**	785 lb/in.	817 lb/in.	546 lb/in.
Weight	1.982 lb/ft	1.958 lb/ft	1.733 lb/ft
Strength to Wt. Ratio	396	417	315

* Flatwise tension strength at 270° F (wet)

** Flatwise tension strength at 270° F (dry)

3.4 FAILURE ANALYSIS

Seven distinct failure modes were observed in these tests:

- Bond failure under heel of flange
- Failure of stitch
- Interlaminar shear failure in skin at toe of flange
- Delamination in bend of flange
- Splitting between back-to-back flanges
- Interlaminar splitting of skin
- Flexural failure of skin.

The failure modes of the static flatwise tension specimens (dry and wet) are indicated in Fig. 32.

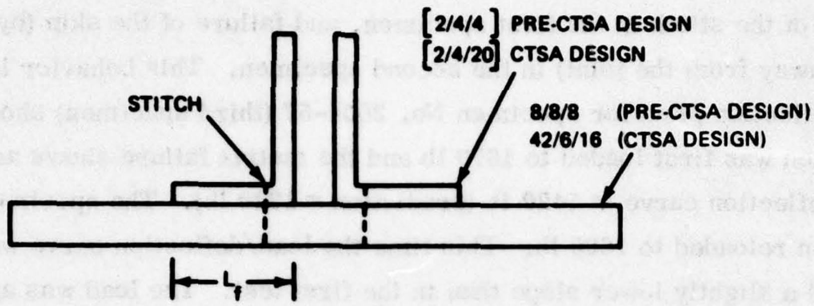
A discussion of each of the failure modes and the methods used to analyze each failure follows.

3.4.1 Bond Failure Under Heel Of Flange (Fig. 34)

The bond failed due to a combination of flatwise and transverse tension and shear stresses under the heel of the flange. The distribution of the flatwise tension stress between the skin and the flange was analyzed by idealizing the skin and flanges as beams coupled by an elastic foundation (Ref. 3). The results of the analysis show a high stress concentration immediately under the heel of the flange, caused primarily by the bending of the skin so as to impose zero slope at the centerline of the joint. The stress concentration can be reduced by increasing the bending stiffness of the skin, as shown in Fig. 35.

The shear stress arises in the bond because of a mismatch in the axial strains (in the 90° direction) at the adjacent faces of the skin and flange. The skin has a tensile strain at the joint due to the bending moment imposing zero slope on the skin at the joint centerline; the flange has zero moment at the heel. The shear stress was analyzed by a simple "shear lag" model per Ref. 1. Again, the magnitude of the shear stress concentration is reduced by increasing the bending stiffness of the skin simply because the strain mismatch is reduced. Combining the flatwise tension, transverse tension due to skin bending, and the shear stresses with a modified Hill-von Mises yield criterion for the matrix enables a successful prediction of the bond

Fig. 34 Bond Failure Under Heel of Flange



		PRE-CTSA DESIGN	CTSA DESIGN CONCEPT I KEVLAR STITCH 2004 - 43	CTSA DESIGN CONCEPT I KEVLAR STITCH 2004 - 57
SKIN LAMINATE $0^o/90^o/\pm45^o$		8/8/8	42/6/16	42/6/16
FLANGE LAMINATE		2/4/4	2/4/8	2/4/20
SKIN BENDING STIFFNESS, D_s	LB-IN.	1524	15178	15178
FLANGE BENDING STIFFNESS, (D_f)	LB-IN.	102	315	1981
FLANGE LENGTH, (L_f)	IN.	0.73	1.0	1.0
MODULUS OF FOUNDATION, (k)	LB/IN^3	17.9×10^6	7.8×10^6	6.8×10^6
BOND STRESSES FOR UNIT LOAD				
FLATWISE TENSION		67	22	19
TRANSVERSE TENSION		95	23	23
SHEAR STRESS		69	15	15

			PRE-CTSA PRED	PRE-CTSA TEST*	2004 - 43 PRED	2004 - 43 TEST*	2004 - 57 PRED	2004 - 57 TEST*
MATRIX FAILURE	-67^oF	LB/IN	—	—	390	388	400	404
MATRIX FAILURE	R.T.	LB/IN	128	120	500	457	520	500
MATRIX FAILURE	260^oF	LB/IN	—	—	390	319	450	488

*As shown by first "jog" in load/deflection curve. Average of three test results

2921-135W

Fig. 35 Variation of Tensile and Shear Stress in Bond.

failure for the three specimen configurations shown in Fig. 35. These specimens were stitched and it should be emphasized that, in each case, bond failure did not cause catastrophic failure of the specimen. The joint continued to carry load until failure of the stitch in the first specimen, and failure of the skin (by interlaminar shear away from the joint) in the second specimen. This behavior is illustrated by the load deflection plots for specimen No. 2004-57 (third specimen) shown in Fig. 36. The specimen was first loaded to 1670 lb and the matrix failure shows as a "jog" in the load/deflection curve at 1420 lb (prediction = 1320 lb). The specimen was unloaded and then reloaded to 1600 lb. This time the load/deflection curve was quite straight and had a slightly lower slope than in the first test. The load was again removed and the specimen reloaded to 1800 lb; the load/deflection curve was straight to 1720 lb, at which point the deflection began to increase nonlinearly, probably due to the onset of interlaminar splitting in the skin. Finally, the load was removed and reapplied. The load/deflection curve was straight, but with diminished slope, and failure occurred at 1800 lb by interlaminar splitting in the skin.

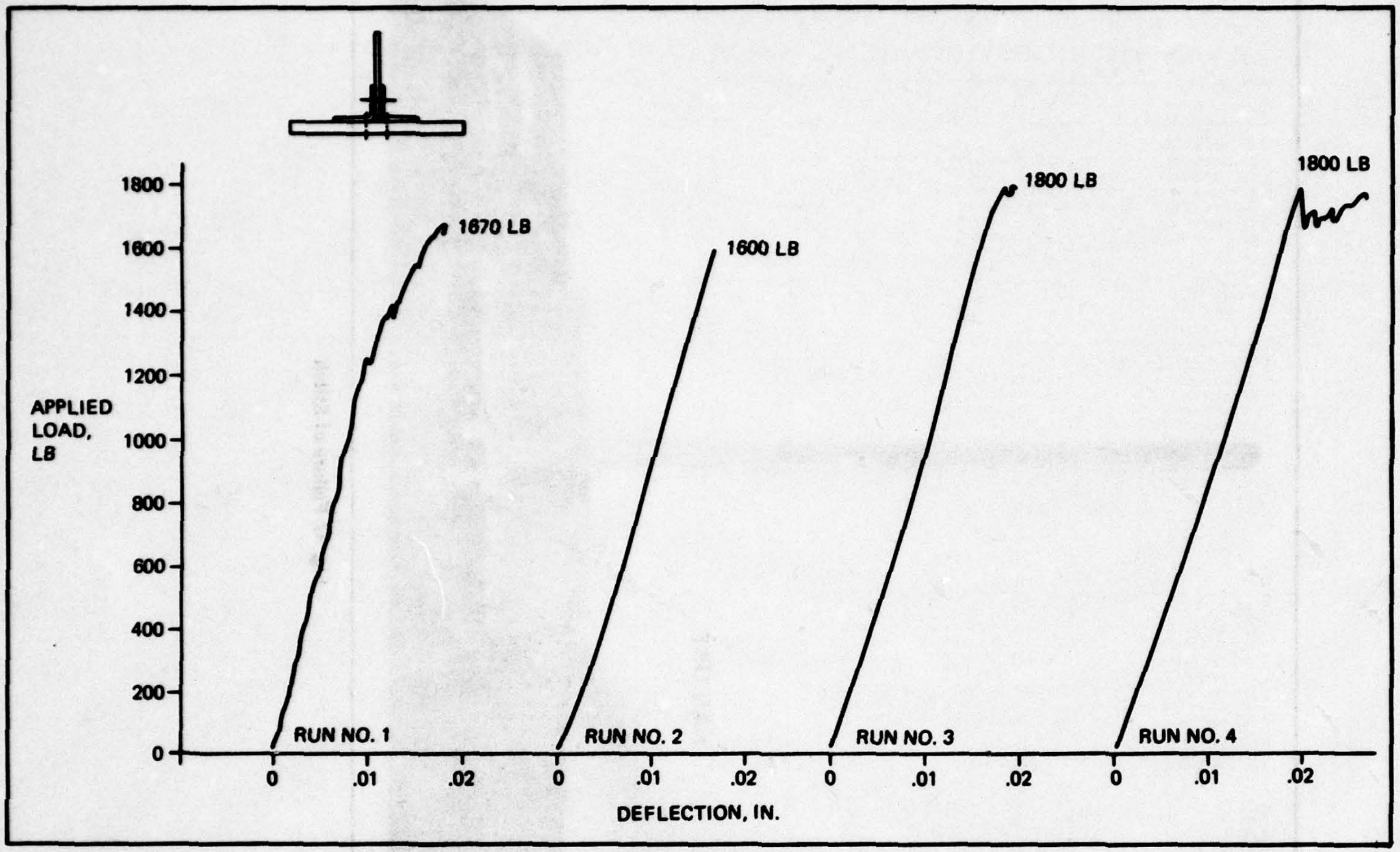
3.4.2 Failure of Stitch (Fig. 37)

The stitch failed in tension, and the failure can be predicted on the basis of a simple "heel and toe" action of the flange with tension in the stitch near the heel and bearing pressure over a small area at the toe of the flange. The matrix can be neglected in this analysis because the matrix failed before the stitch as a result of the combination of high flatwise tension and shear stress at the heel. In fact, the stitch acts as a form of crack stopper to the spread of the bond failure and the joint carries further load after the bond failure.

3.4.3 Interlaminar Shear Failure Of Skin (Fig. 38)

This failure was not a failure of the joint, but occurred in the skin close to the toe of the flange where the overall section changes abruptly on the test specimens. This abrupt change could be eliminated in future designs by tapering the flange from heel to toe.

Analysis of the specimens that failed in this way shows evidence of a nonuniform load introduction. Anticlastic curvature of the skin, coupled with the bending flexibility of the roller, caused the load to be concentrated at the outer edges of the specimen. A simple analysis shows the roller to be in contact with the skin surface over



2921-134W

Fig. 36 Specimen 2004-57 Load/Deflection History

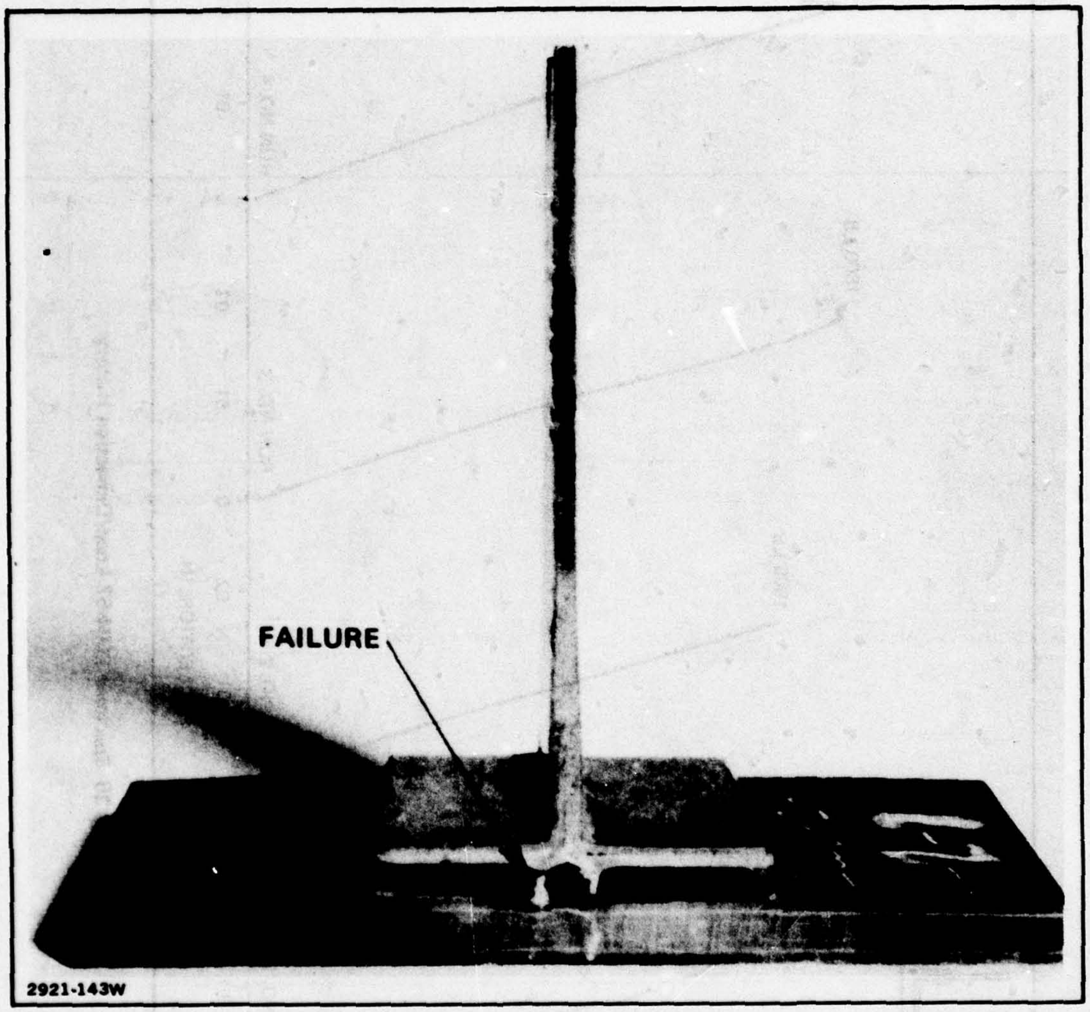


Fig. 37 Failure of Stitch

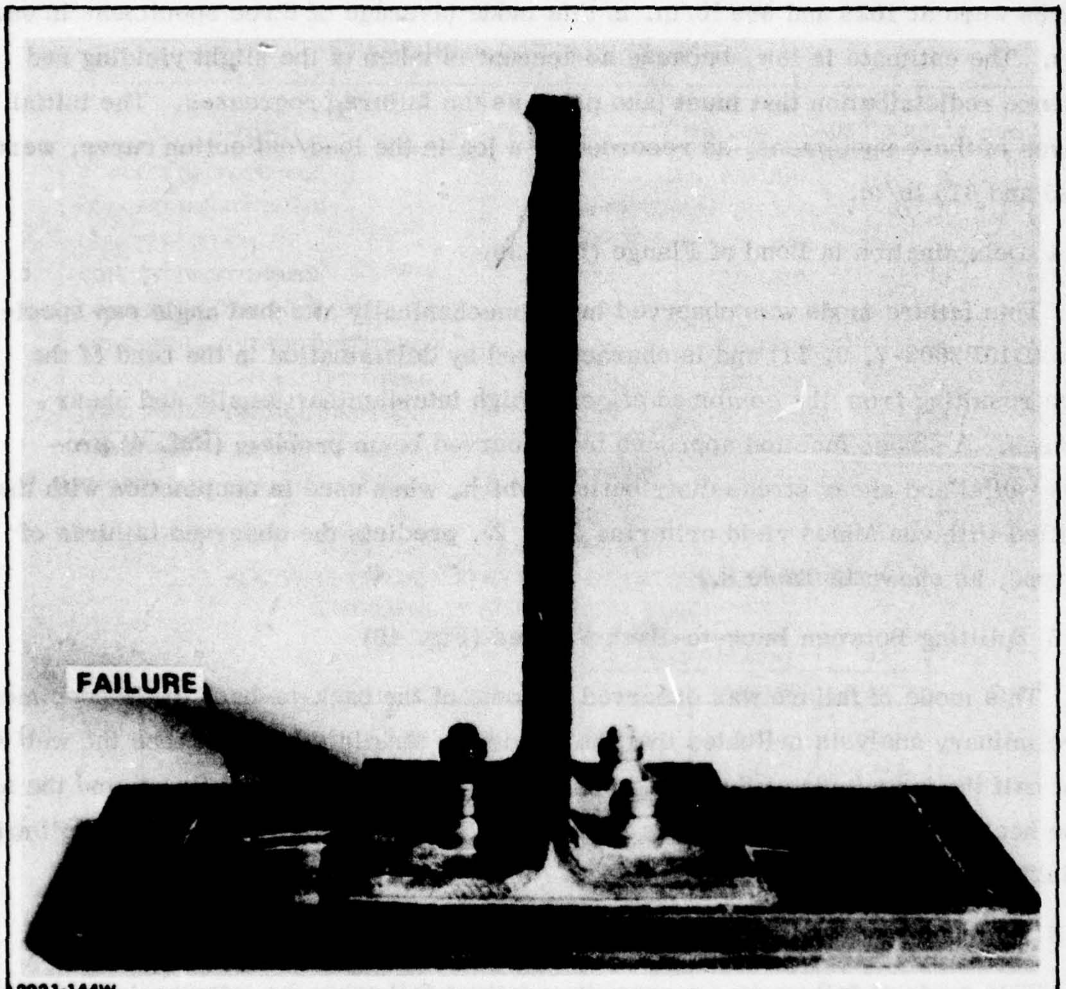


Fig. 38 Interlaminar Shear Failure in Skin at Toe of Flange

only 0.40 in. at each edge, and this was confirmed by the appearance of indentation marks, typically about 1/2 in. long, on the surface of the specimens.

Failure analysis based on the maximum interlaminar shear stresses under the peak bearing location gives an estimated failure load of 603 lb/in. for the joint. Test failures were at 1028 and 869 lb/in. in this mode (average of three specimens in each case). The estimate is low, because no account is taken of the slight yielding and pressure redistribution that must take place as the failure progresses. The initial failures of these specimens, as recorded by a jog in the load/deflection curve, were at 785 and 615 lb/in.

3.4.4 Delamination in Bend of Flange (Fig. 39)

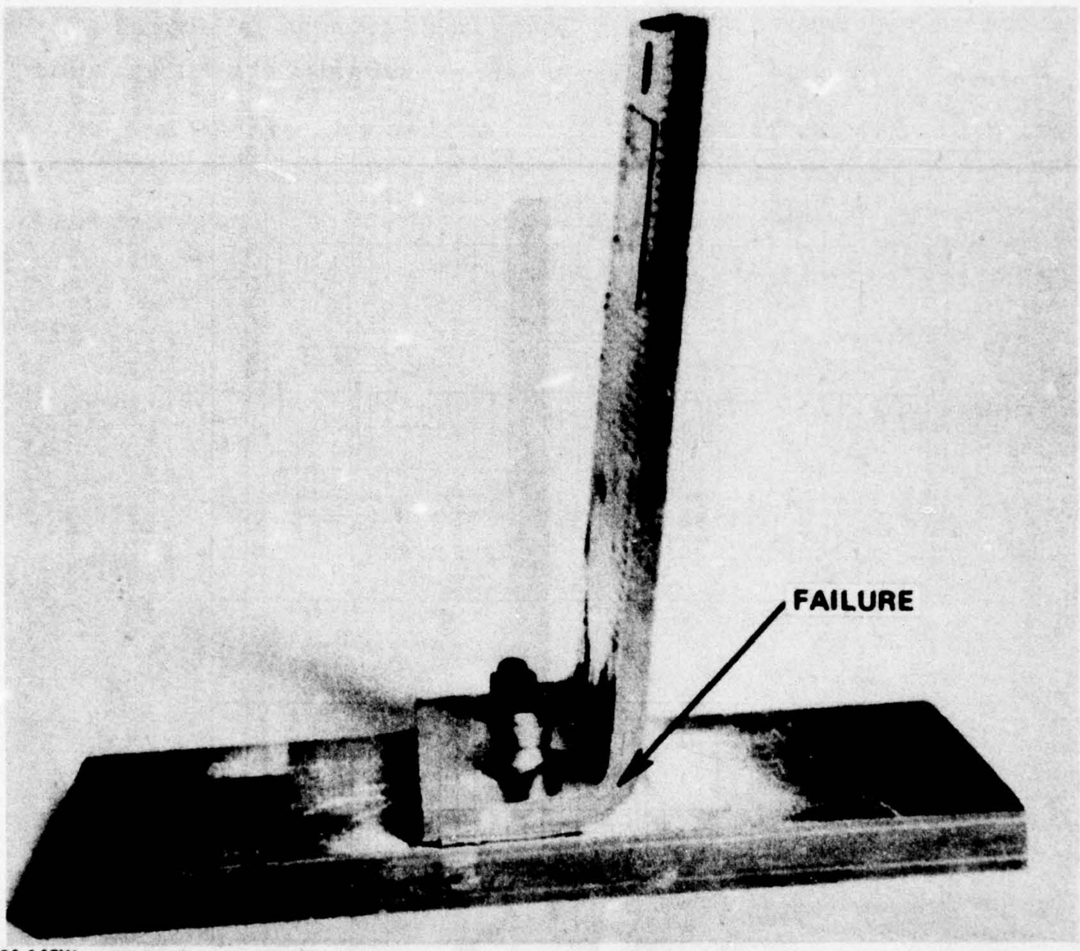
This failure mode was observed in the mechanically attached angle cap specimens (D10B2003-7, 9, 11) and is characterized by delamination in the bend of the flange resulting from the combined effect of high interlaminar tensile and shear stresses. A stress function approach to the curved beam problem (Ref. 4) produces radial and shear stress distributions which, when used in conjunction with the modified Hill-von Mises yield criterion (Ref. 2), predicts the observed failures of this type, as shown in Table 8.

3.4.5 Splitting Between Back-to-Back Flanges (Fig. 40)

This mode of failure was observed in some of the back-to-back angle specimens. A preliminary analysis indicates that the maximum tensile stress between the web was about half the magnitude of the maximum tensile stress between the flange and the skin at the heel of the flange. It appears that this failure was a secondary failure following the initial failure at the heel of the flange.

3.4.6 Interlaminar Splitting of the Skin (Fig. 41)

This mode of failure was a secondary failure following the interlaminar shear failure of the skin. It appears that the interlaminar shear crack propagated diagonally through the laminate until it reached the 90° (chordwise) layers, at which point the crack propagated in the chordwise direction along the 90° layers. Analagous behavior is observed in steel reinforced concrete beams where diagonal tension cracks often result in splitting of the concrete along the tension reinforcement.



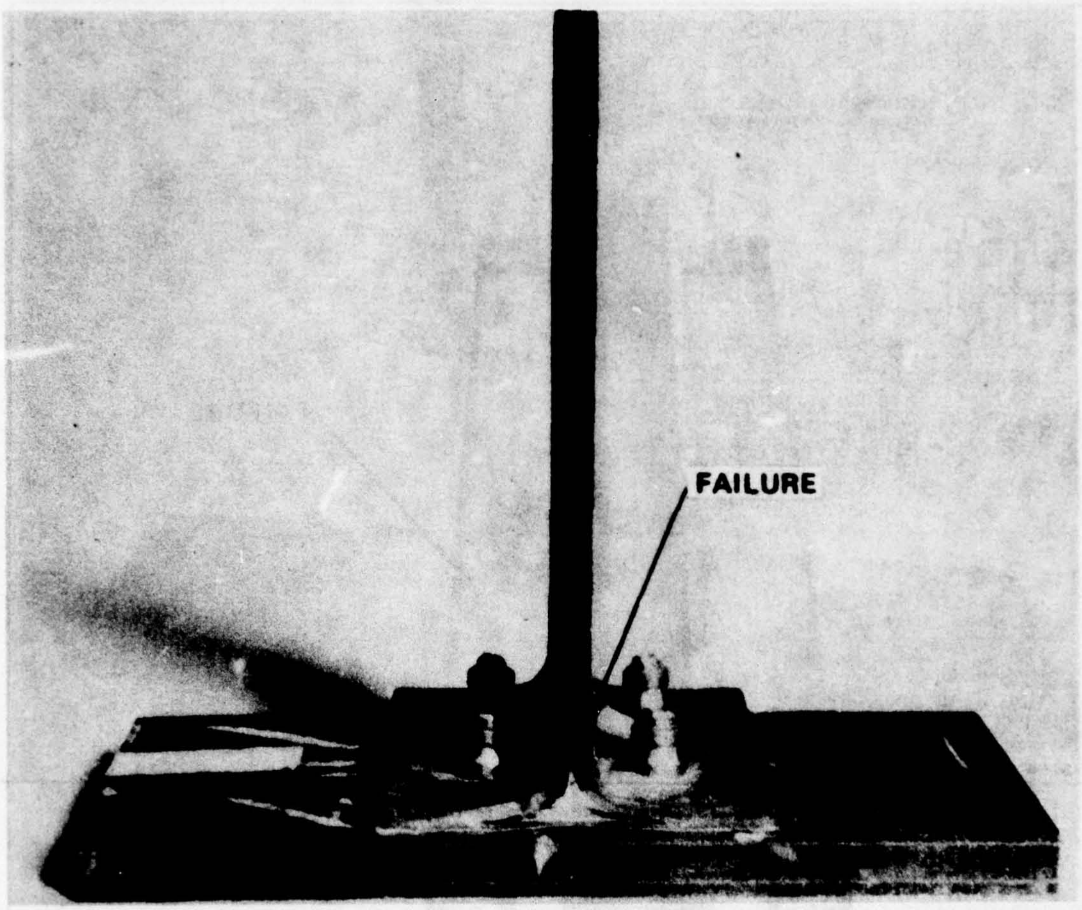
2921-145W

Fig. 39 Delamination in Bend of Flange

TABLE 8
TEST RESULTS, PREDICTED VS ACTUAL (DRY)

TEMP	PREDICTED (LB/IN.)	TEST LOAD (LB/IN.) COUPON NO. 1	2	3	LB/IN. (AVG)
-67° F	632	659	643	635	646
RT	678	631	683	675	663
270° F	514	548	536	556	546

2921-197



2921-146W

Fig. 40 Splitting Between Back-To-Back Flanges

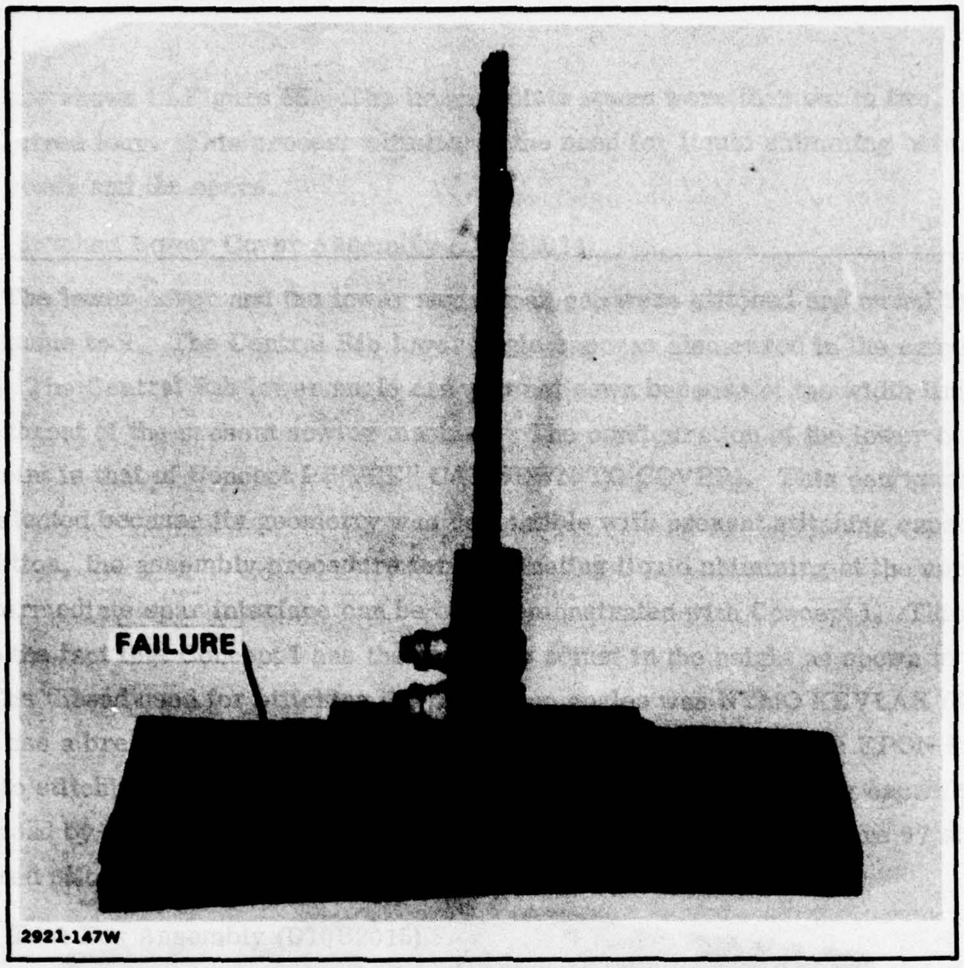


Fig. 41 Interlaminar Splitting of Skin

3.4.7 Flexural Failure of the Skin (Fig. 42)

Measurements of the skins of the specimens that failed in flexure (D10B2005-43-3 and D10B2007-19-3) indicated markedly reduced per ply thicknesses resulting in bending stiffnesses which were significantly lower than those calculated using nominal layer thicknesses (41.7% and 16.8% reductions respectively). The results of tensile tests on stitched coupons indicate that the strength reduction caused by the stitch is equivalent to that caused by a 1/16 inch diameter open hole. This fact, used in conjunction with the actual bending stiffnesses and our notched laminate strength prediction method (Ref. 5), indicate the susceptibility of these specimens to flexural failure at -67° F as indicated in Table 9.

Fig. 42 Flexural Failure of Skin

TABLE 9
TEST RESULTS, PREDICTED VS ACTUAL

SPECIMEN NO.	TEMP.	SKIN THICKNESS (IN.) MEASURED/NOMINAL	FAILURE LOAD (LB/IN.)	
			PREDICTED	TEST
D10B 2006-43-3	-67°F	.281/.336	573	720
D10B 2007-19-3	-67°F	.316/.336	727	736

2921-198

SECTION IV

SUBCOMPONENT DESIGN AND THERMOPLASTIC SEALING

4.1 SUBCOMPONENT TEST BOX DESIGN

The test box (Fig. 43) was designed to the following ultimate loads:

- 50 psi internal pressure
- 300 lb/in. shear in the intermediate spars
- 1200 lb/in. shear in the front/rear spars.

The selected representative test areas were:

- lower cover/intermediate spar joints (stitched)
- upper cover/intermediate spar joints (bolted)
- the upper cover periphery for the thermoplastic sealing test.

The test box representative test area is shown in Fig. 44.

4.1.1 Front/Rear Spar Design - Graphite/Epoxy (Fig. 45)

The front and rear spars were designed to carry 1200 lb/in. ultimate shear load and 50 psi ultimate pressure. The spar cap is a 46 ply laminate (6-12-28). The spar web is a 31 ply laminate (3-12-16). The spar to skin fasteners are 0.25 in. dia countersunk titanium bolts (GB510F4). Because the front/rear spars are not part of the structural test area, they were designed with ample margin of safety.

4.1.2 Upper Cover Design - Graphite/Epoxy (Fig. 46)

The upper cover is a 50 ply graphite/epoxy laminate. The skin is mechanically fastened to the intermediate spars with the following fasteners:

- GN512F3 (0.250 inch dia - "O" ring rivnut)
- GB510F4 (0.250 inch dia - "O" ring bolt and nut)
- C2R1868 (0.281 inch dia - interference fit rivnut).

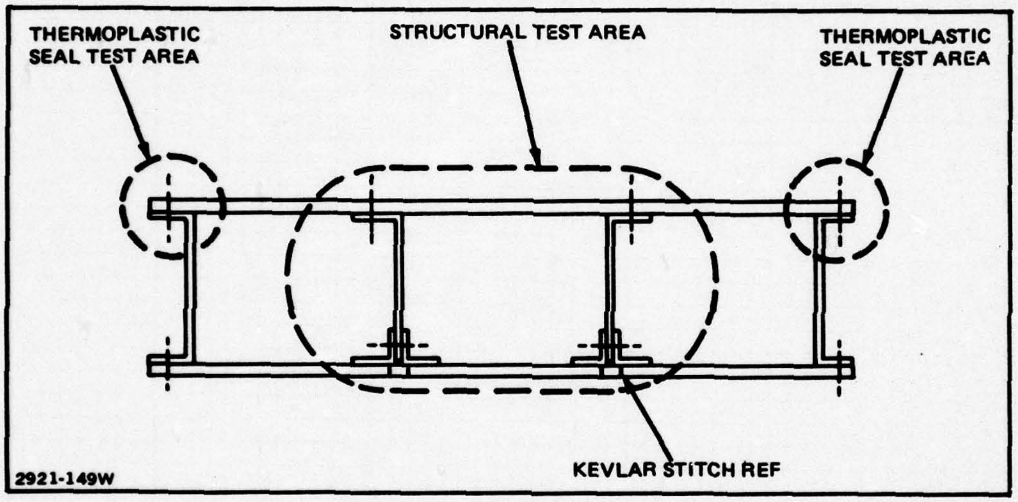
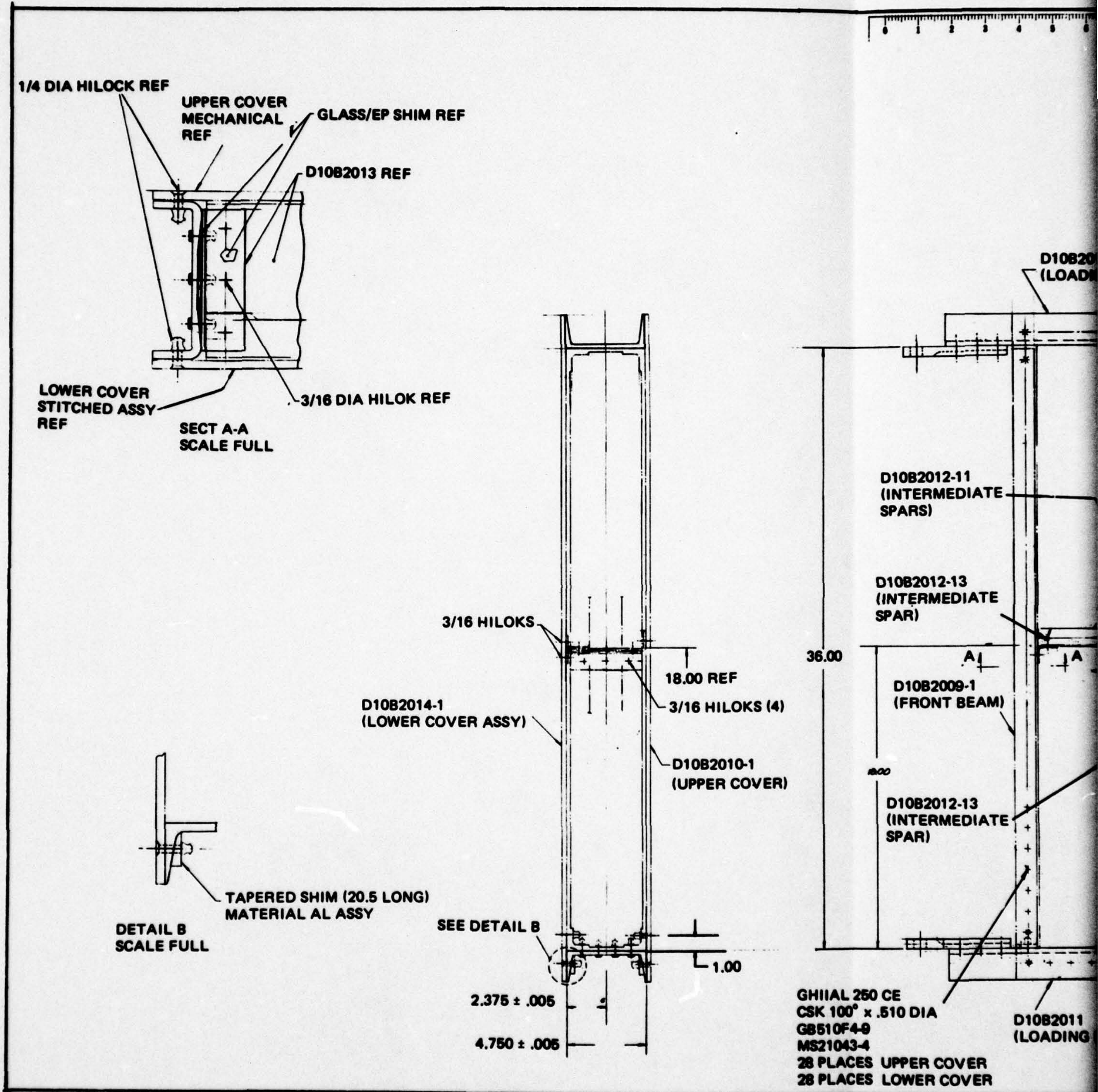


Fig. 44 Test Box Representative Test Area



1/4 DIA HILOCK REF
UPPER COVER MECHANICAL REF
GLASS/EP SHIM REF
D10B2013 REF
LOWER COVER STITCHED ASSY REF
3/16 DIA HILOK REF
SECT A-A
SCALE FULL
3/16 HILOKS
18.00 REF
3/16 HILOKS (4)
D10B2014-1
(LOWER COVER ASSY)
D10B2010-1
(UPPER COVER)
TAPERED SHIM (20.5 LONG)
MATERIAL AL ASSY
DETAIL B
SCALE FULL
SEE DETAIL B
1.00
2.375 ± .005
4.750 ± .005
36.00
D10B2012-11
(INTERMEDIATE SPARS)
D10B2012-13
(INTERMEDIATE SPAR)
D10B2009-1
(FRONT BEAM)
D10B2012-13
(INTERMEDIATE SPAR)
GHIIAL 250 CE
CSK 100° x .510 DIA
GB510F4-9
MS21043-4
28 PLACES UPPER COVER
28 PLACES LOWER COVER
D10B2011

2921-150W

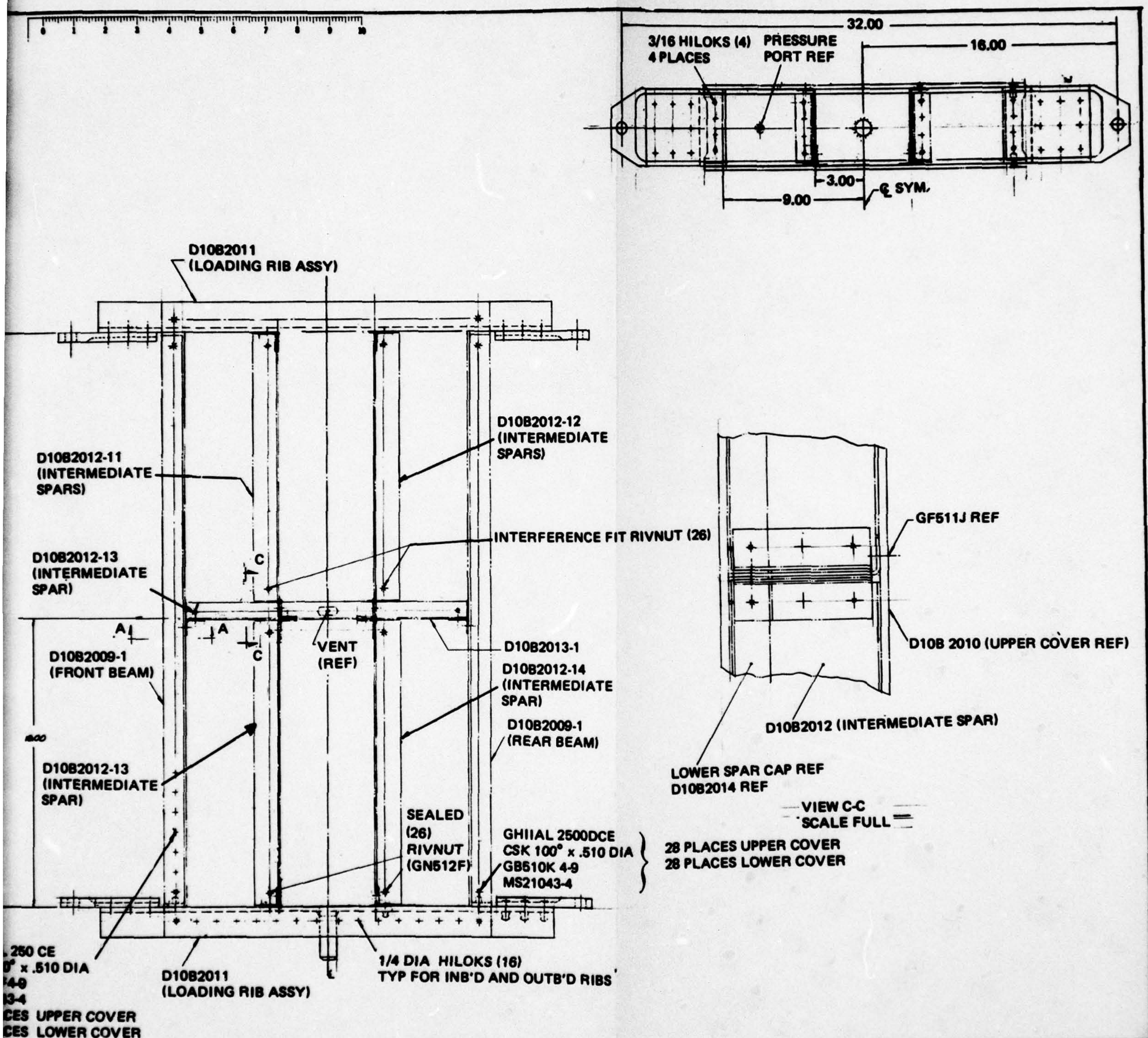
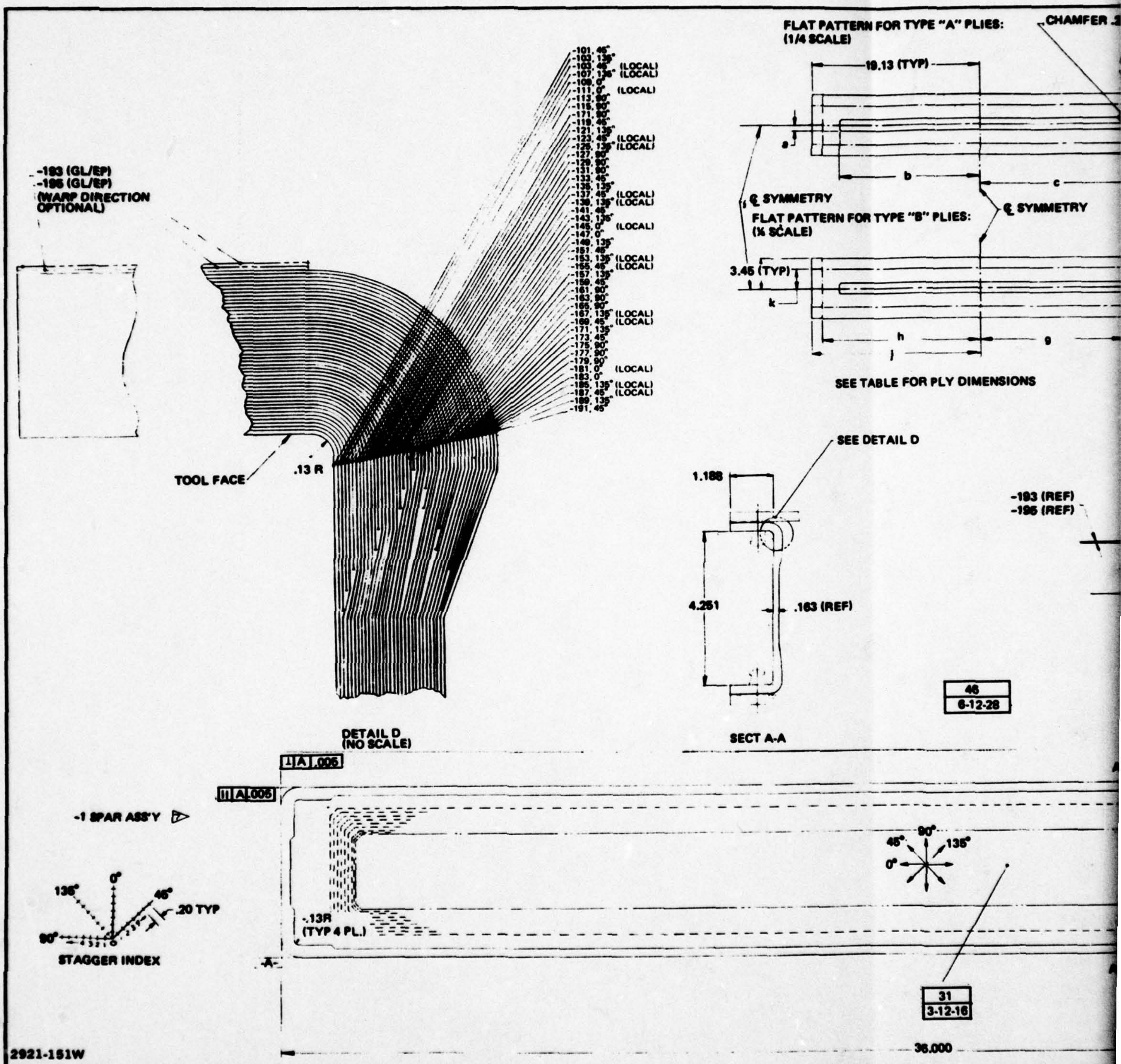


Fig. 43 Test Box



FLAT PATTERN FOR TYPE "A" PLIES:
(1/4 SCALE)
CHAMFER
19.13 (TYP)
a
b
c
℄ SYMMETRY
FLAT PATTERN FOR TYPE "B" PLIES:
(¼ SCALE)
℄ SYMMETRY
3.45 (TYP)
k
h
j
g
SEE TABLE FOR PLY DIMENSIONS
-193 (GL/EP)
-195 (GL/EP)
(WARP DIRECTION OPTIONAL)
TOOL FACE
.13 R
SEE DETAIL D
1.188
4.261
.163 (REF)
-193 (REF)
-195 (REF)
46
6-12-28
DETAIL D
(NO SCALE)
SECT A-A
.005
-1 SPAR ASS'Y
90°
45°
135°
0°
135°
0°
45°
.20 TYP
90°
STAGGER INDEX
.13R
(TYP 4 PL.)
A
31
3-12-16
36.000
2921-151W

1

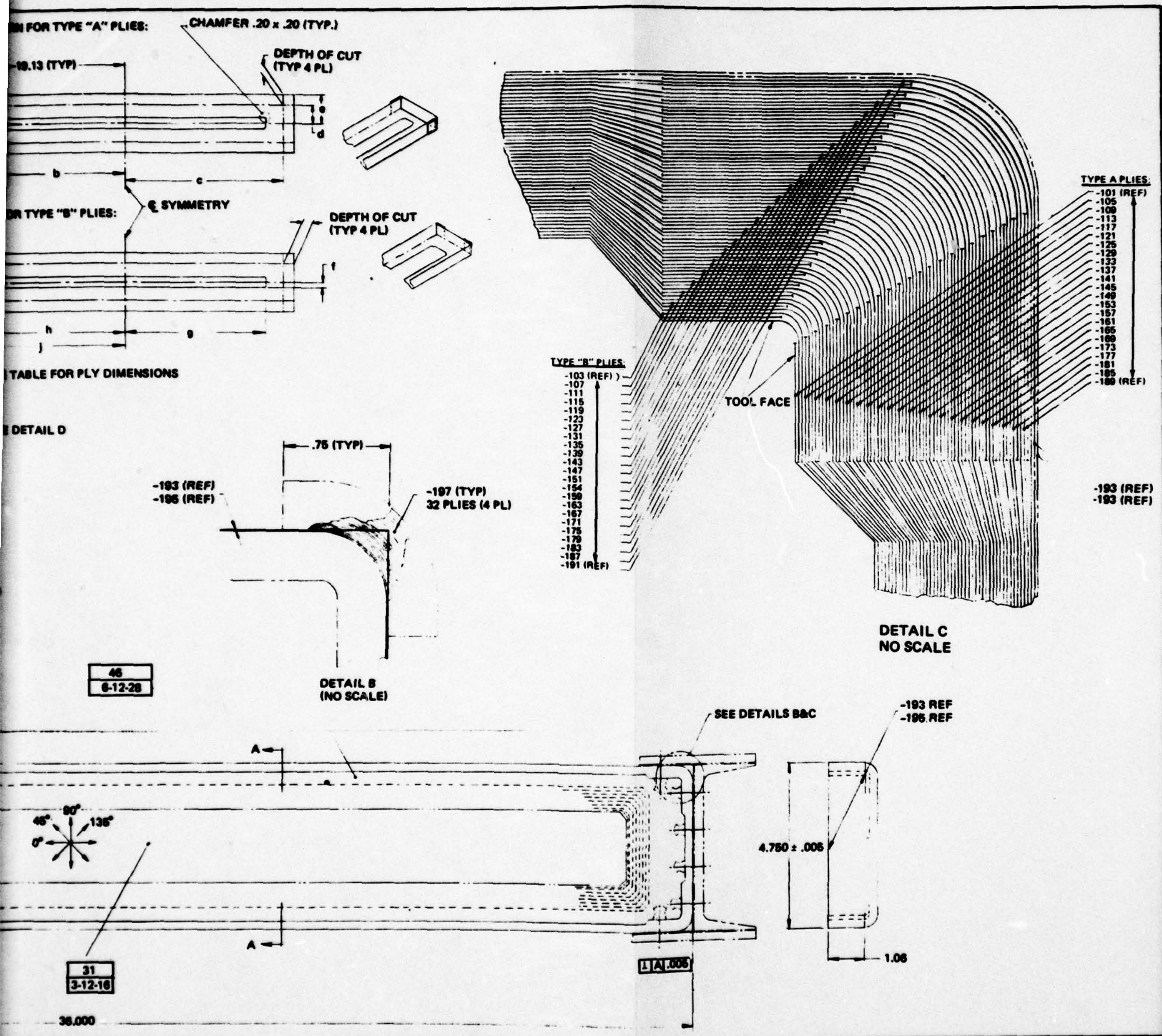


Fig. 45 Front/Rear Spar (1 of 2)

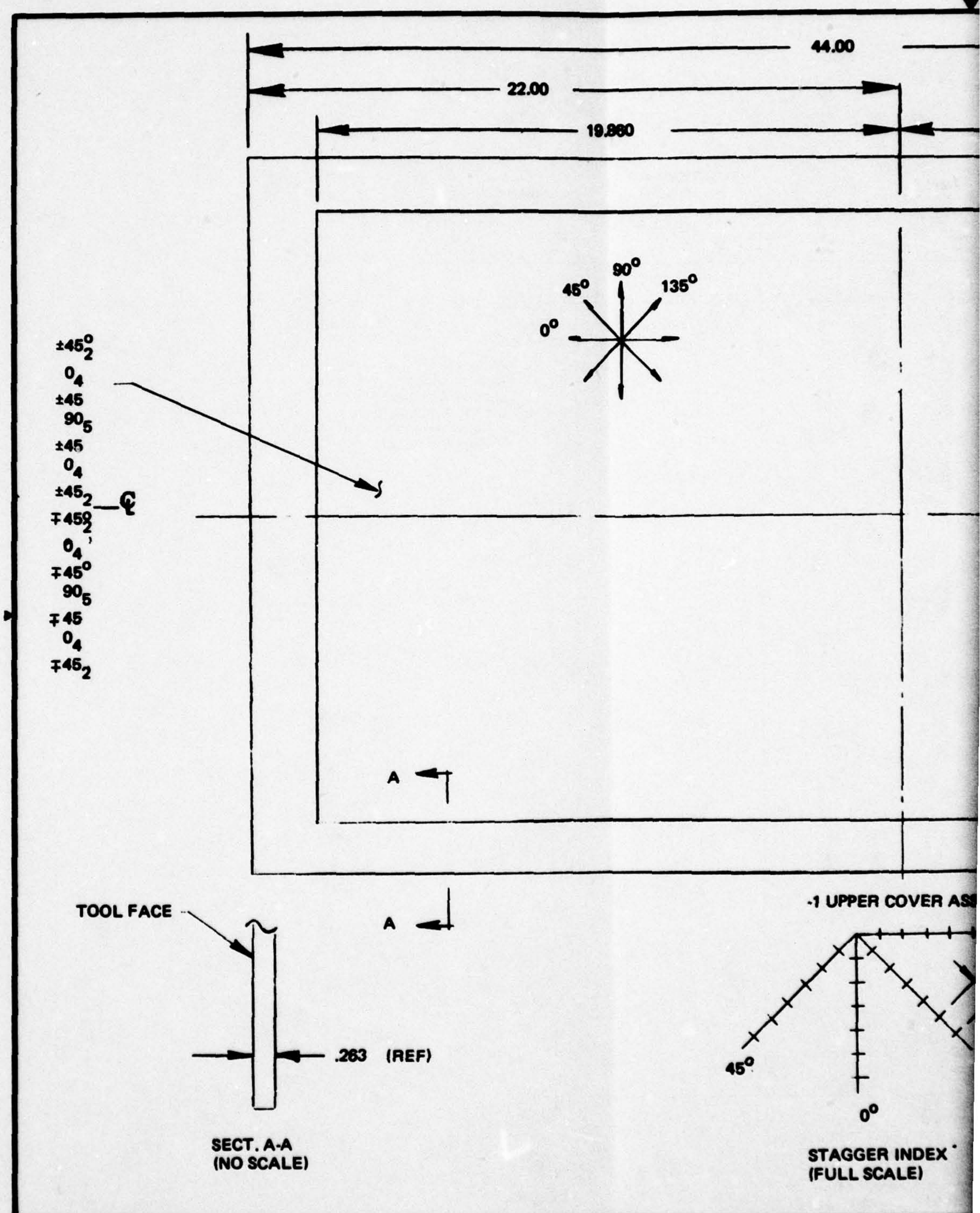
NOTES:

1. MANUFACTURE SPAR PER GR1008
2. TOLERANCES:
   a. GL/EP LAMINA THICKNESS TO BE .0084 -.0096.
   b. Gr/Ep LAMINA THICKNESS TO BE.0050 -.0055..
   c. MAXIMUM DEVIATION FROM INTENDED FIBER ORIENTATION SHALL NOT EXCEED 1°.
3. EACH SPECIMEN SHALL BE ULTRASONICALLY & DIMENSIONALLY INSPECTED AFTER CURING. IN ADDITION, ANY FLAWS OR IRREGULARITY IN FIBER ORIENTATION, SPACING, FINISH, ETC., SHALL BE REPORTED. ALL RADII MUST BE RADIOGRAPHICALLY INSPECTED FOR VOIDS.
4. $\frac{X}{L-M-N}$ THIS CODE INDICATES THE TOTAL COMBINED NUMBER AND TYPE OF PILES NOTED:
   X = TOTAL NO. OF PLIES
   L = NO. OF 0° PLIES
   M = NO OF 90° PLIES
   N = NO. OF 45° & 135° PLIES COMBINED
5. MACHINED EDGES SHALL BE FREE OF NOTCHES OR OTHER LOCALIZED IMPERFECTIONS.
6. EDGE OF TAPE PASSES THRU BASE POINT FOR 0°, 45°, 90°, & 135° LAMINA WITH "0" STAGGER INDEX. STAGGER INDEX DOES NOT APPLY FOR LAMINA LESS THAN 3 IN. WIDE IN THE FILAMENT DIRECTION.

△7 -1 ASS'Y TO BE NET MOLDED.

PLY DIMENSIONS														
TYPE "A"							TYPE "B"							
DASH NO.	ORIENT DEG	a	b	c	d	e	DASH NO.	ORIENT DEG.	f	g	h	j	k
-101	45	–	–	17.75	2.07	3.20	-103	135	–	–	17.75	18.88	2.07
-105	45	1.05	15.96				-107	135	1.15	16.06			
-109	0	–	–				-111	0	1.25	16.16			
-113	90	–	–	17.75	2.07	3.20	-115	90	–	–	17.75	18.88	2.07
-117	90	–	–	17.78	2.09	3.26	-119	45	–	–	17.78	18.94	2.09
-121	135	–	–				-123	45	1.35	16.26			
-125	135	1.45	16.36				-127	90	–	–			
-29	90	–	–	17.78	2.09	3.25	-131	90	–	–	17.78	18.94	2.09
-33	45	–	–	17.80	2.12	3.30	-135	135	–	–	17.80	18.99	2.12
-37	45	1.75	16.66				-139	135	1.65	16.56			
-41	45	–	–				-143	135	–	–			
-145	0	1.75	16.66	17.80	2.12	3.30	-147	0	–	–	17.80	18.99	2.12
-49	135	–	–	17.83	2.15	3.36	-51	45	–	–	17.83	9.03	2.15
-153	135	1.65	16.56				-155	45	1.55	16.46			
-157	135	–	–				-159	45	–	–			
-161	90	–	–	17.83	2.15	3.36	-163	90	–	–	17.83	9.03	2.15
-165	90	–	–	17.85	2.17	3.41	-167	135	1.45	16.36	17.85	19.09	2.17
-169	45	1.35	16.26				-171	135	–	–			
-173	45	–	–				-175	90	–	–			
-177	90	–	–	17.85	2.17	3.40	-179	90	–	–	17.85	19.09	2.17-
-181	0	1.25	16.16	17.88	2.19	3.45	-183	0	–	–	17.88	19.13	2.19
-185	135	1.15	16.06				-187	45	1.05	15.96			
-189	135	–	–	17.88	2.19	3.45	-191	45	–	–	17.88	19.13	2.19

Fig. 45 Front/Rear Spar (2 of 2)



TOP 73-1 12-73

2921-152W

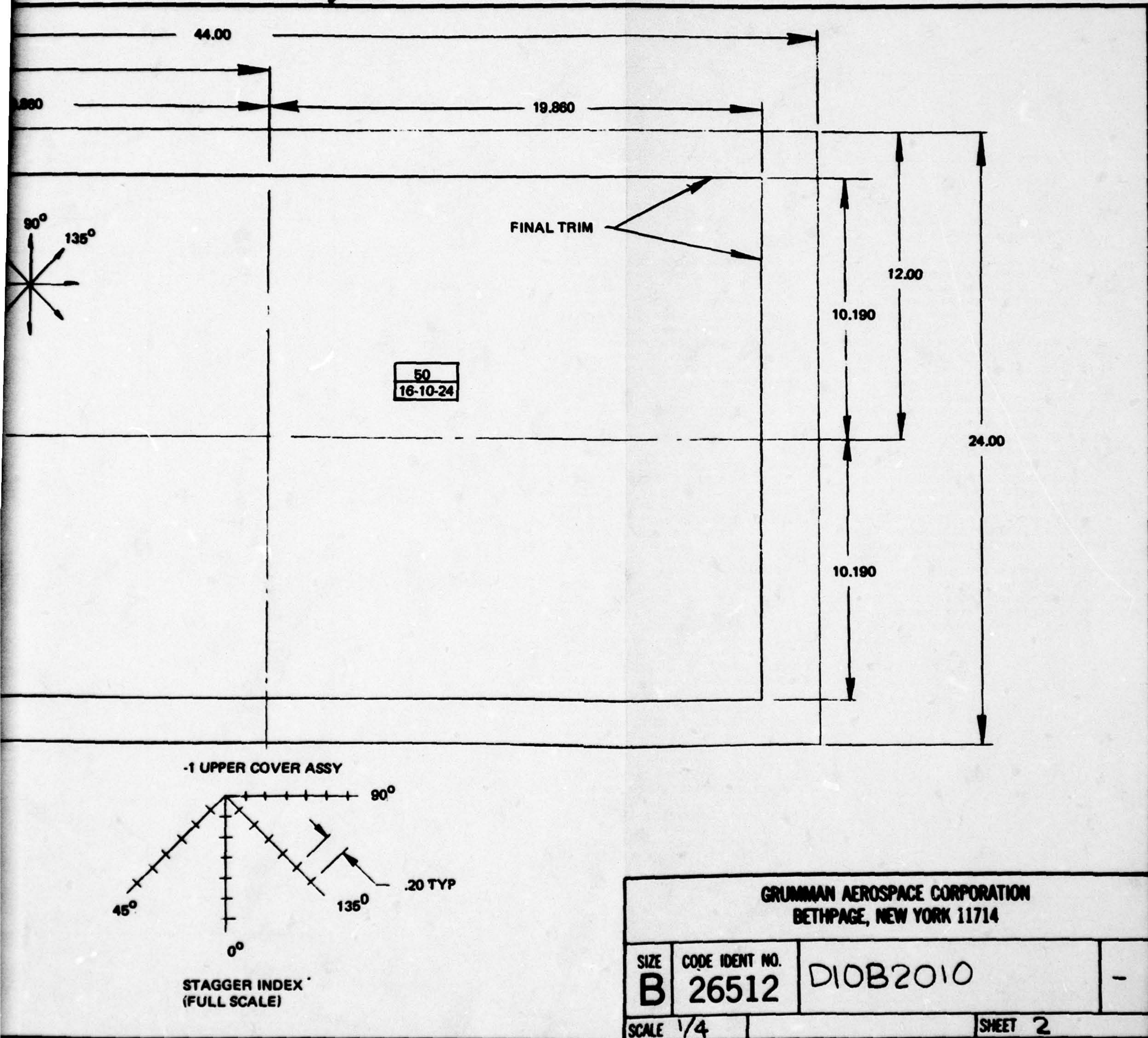


Fig. 46 Upper Cover

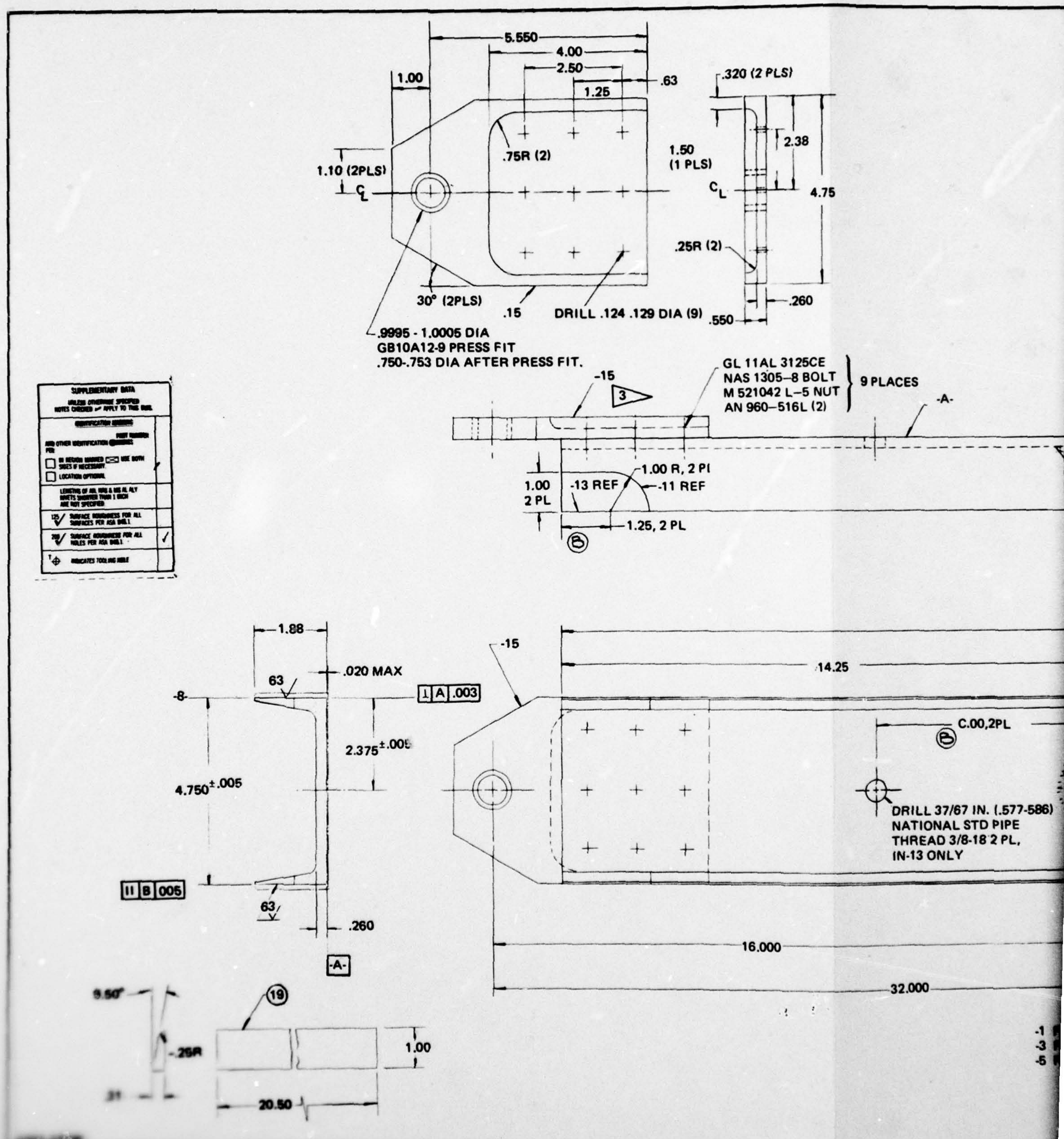
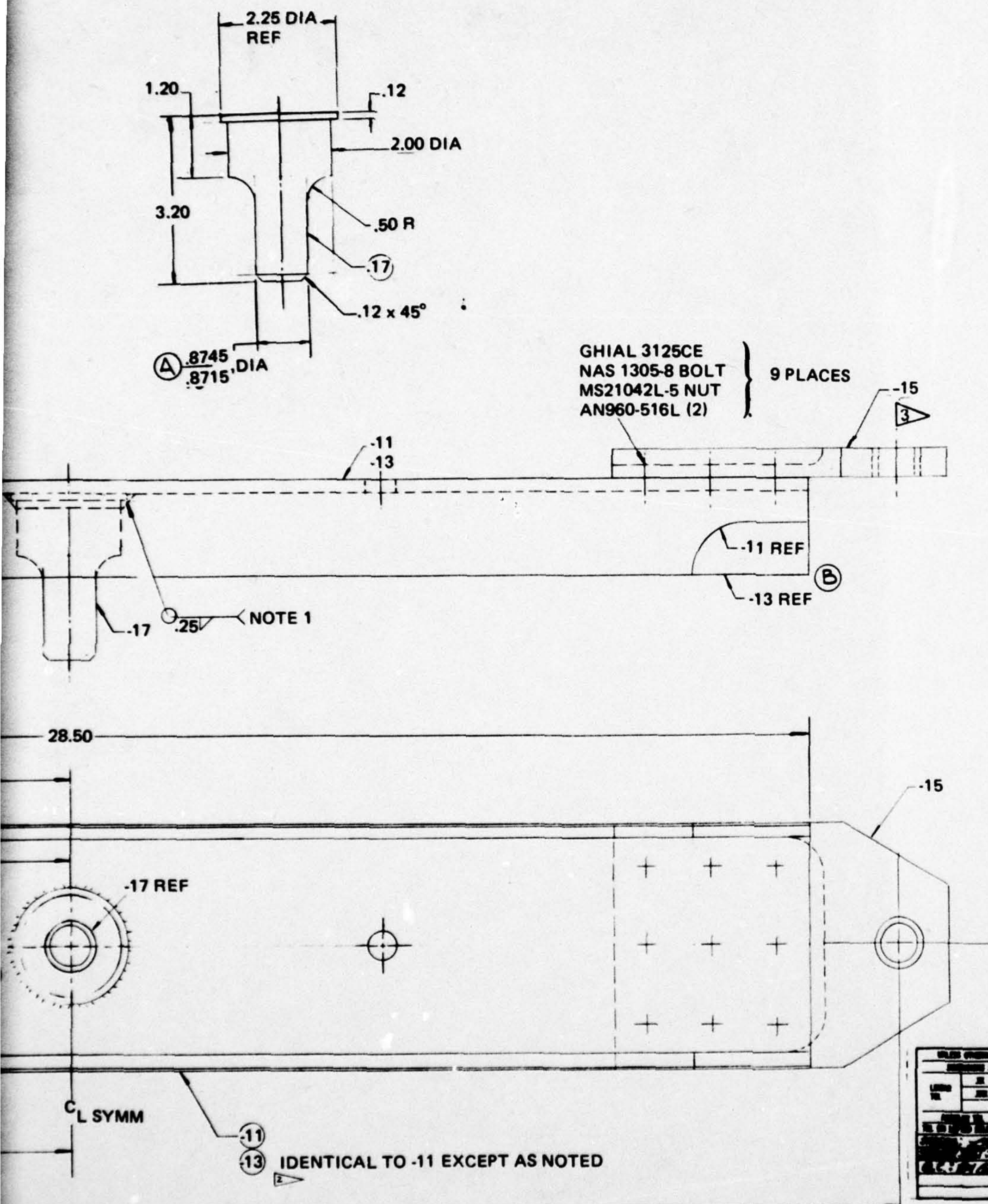


Fig. 47 Closure Yoke



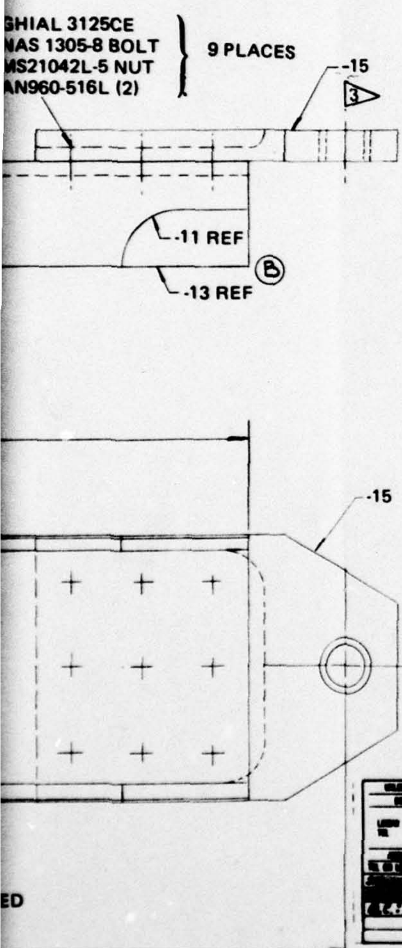
NOTES:
1. WELD PER MIL-W-B611 (GSS 6203).
2. WELDING OF -17 TO BE PERFORMED BEFORE FINISH MACHINING OF -13.
3. IF REQD LIQUID SHIM WITH GM4004221 PER GSS11700.

RIB ASSY CLOSURE

26512

RIB WELDED ASSY
RIB ASSY
RIB ASSY

2



NOTES:
1. WELD PER MIL-W-B611 (GSS 6203).
2. WELDING OF -17 TO BE PERFORMED BEFORE FINISH MACHINING OF -13.
3. IF REQD LIQUID SHIM WITH GM4004221 PER GSS11700.

F33615-77-C-3071

RIB ASSY
CLOSURE

26512

The cover critical loading is:

$N_x = 118$ lb/in.

$N_y = 118$ lb/in.

$N_{xy} = 1200$ lb/in.

$M_{yy} = -218$ in.-lb/in. (tension inner face)

which occurs at the intersection of the cover and intermediate spars. Using STIFFNESS 6 (HP 9830A) computer program, the layer stresses are calculated. The margins are as follows:

90° ply	MS = 0.97	TEMP = 270° F (dry)
45° ply	MS = 0.39	

4.1.3 Closure Rib Design - Steel (*Fig.* 47)

The closure rib was designed with a safety factor of three on ultimate load. The applied load to produce a 1200 lb/in. shear flow in the test box is found from:

$$q = \frac{T}{2A} = \frac{P(H)}{2A}$$

solving for P

$$P_{ult} = \frac{(2)(90)(1200)}{32} = 6750 \text{ lb}$$

where $A = 5 \times 18 = 90$ in.^{2}

$q = 1200$ lb/in. (ultimate)

$H = 32$ in.

∴ The design load for the rib is:

$$P_{design} = 3 \times 6750 = 20,250 \text{ lb}$$

4.1.4 Intermediate Spar Design - Graphite/Epoxy (Fig. 48)

The intermediate spars were designed to carry 300 lb/in. shear in conjunction with a 300 lb/in. flatwise tension load. All four intermediate spars have the same "angle" type configuration. The laminate consists of thirty-two (32) plies with a 2-6-24 ply orientation. This configuration was tested in the element phase of this program (Fig. 11). The ultimate flatwise tension load at 270° F (dry) was 546 lb/in.

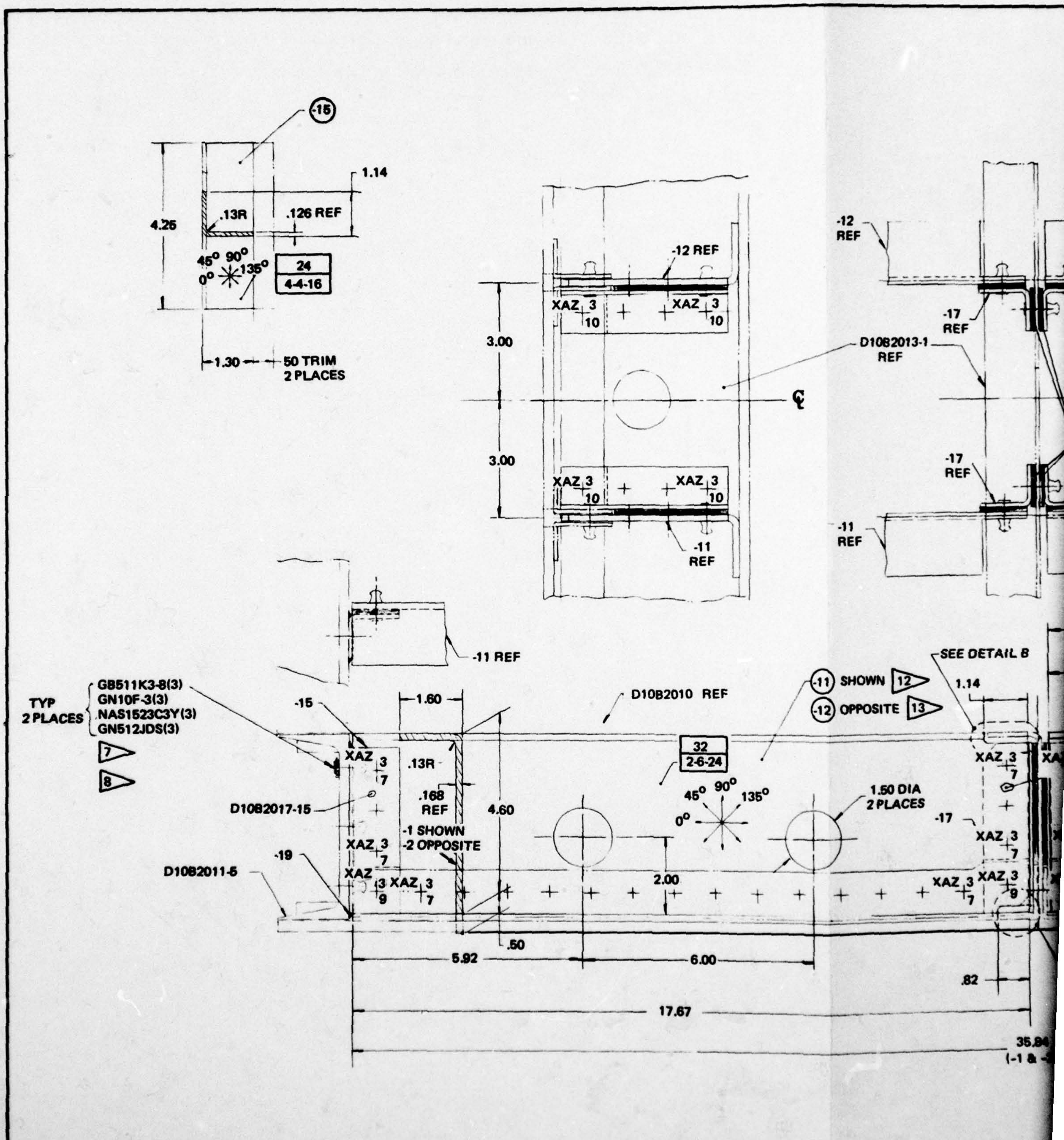
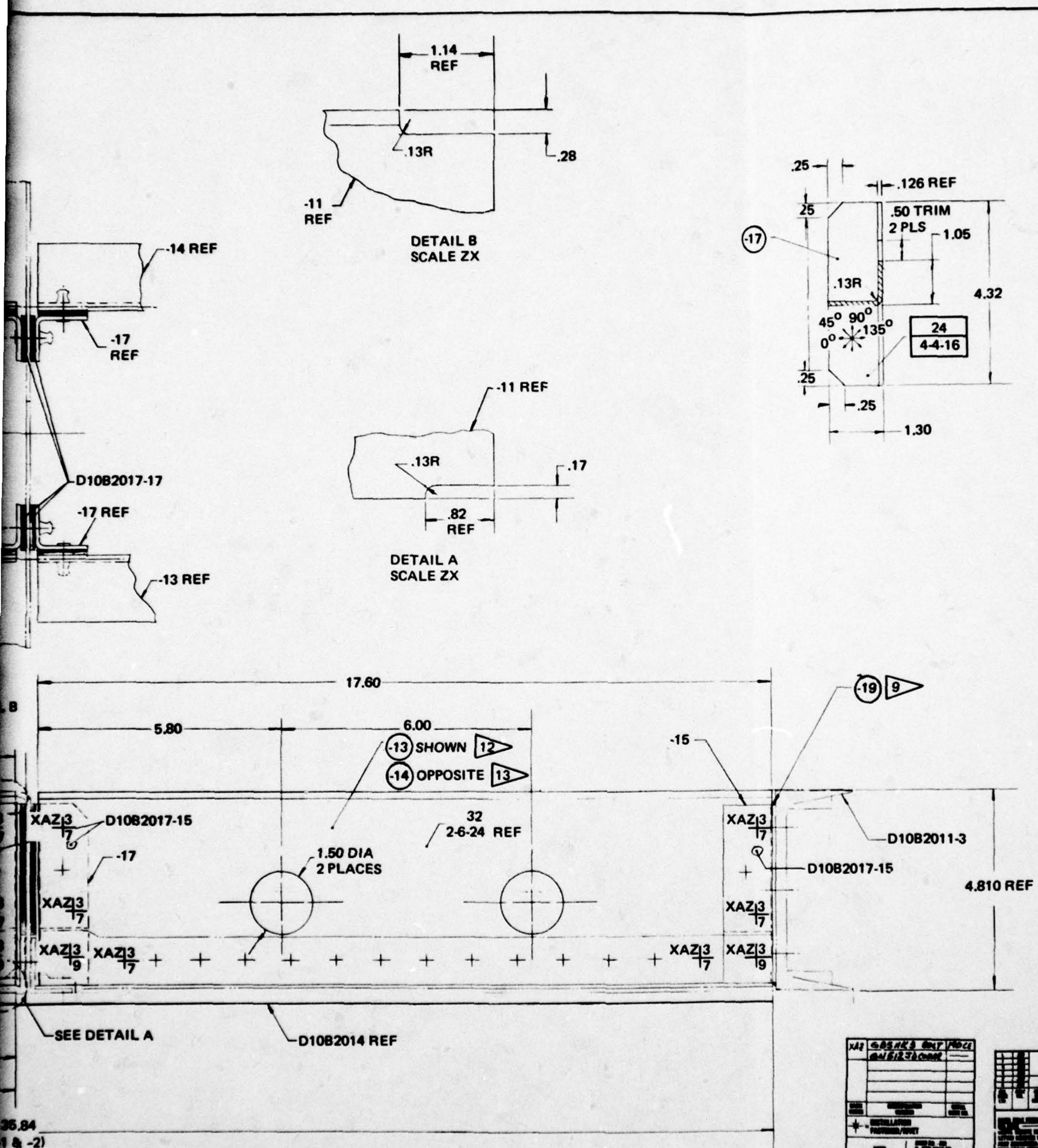
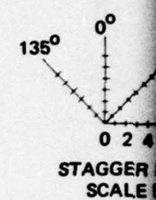


Fig. 48 Intermediate Spars Assy & Installation





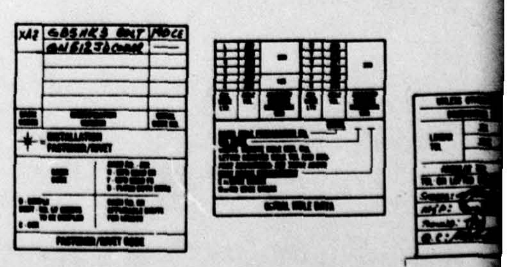
NOTES:

1. MANUFACTURE F
2. TOLERANCES: (A
(B
3. PART SHALL BE U
CURING, IN ADDIT
SPACING, FINISH
RADIOGRAPHICA
4. THIS CODE INDIC
NOTED:

X
L-M-N

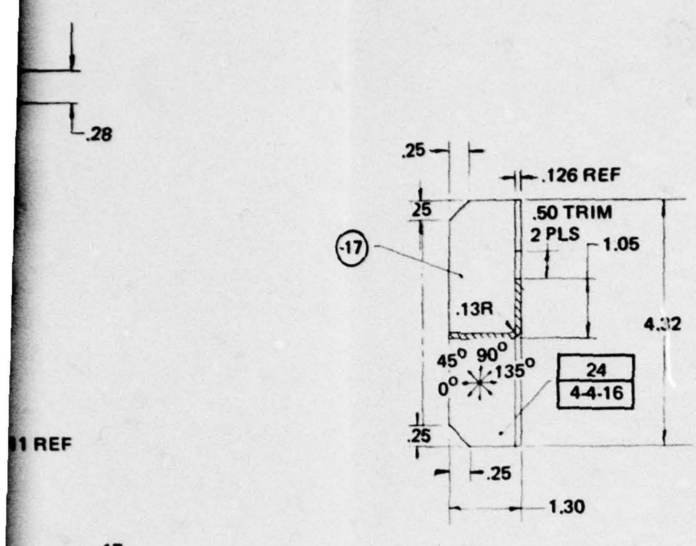
X = TOTAL
L = NO OF
M = NO OF
N = NO OF

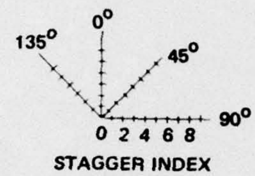
5. MACHINED EDGE
IMPERFECTIONS,
6. EDGE OF TAPE P
LAMINA WITH "0
THAN 3 N WIDE I
7. OVERCOAT FAST
8. COAT BOLTS SHA
9. APPLY – 19 (SEA
REAR SPAR
10. DIMENSIONS NO
11. -1 and -2 ASSY TO
12. MAKE FROM -1
13. MAKE FROM -2



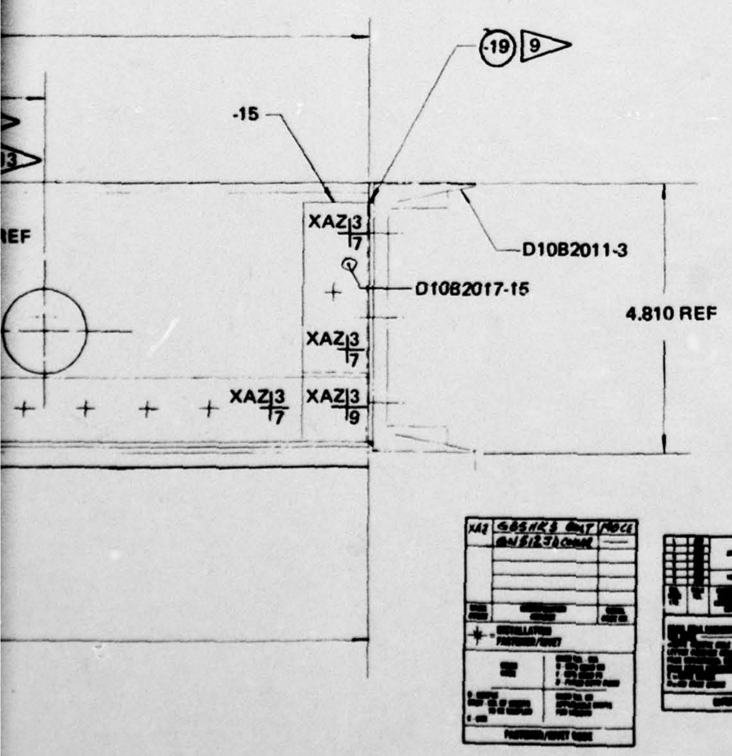
2

-1 SHOWN ~ SPAR LAMINATE ASSY
-2 OPP ~ SPAR LAMINATE ASSY
-3 SHOWN ~ SPAR LAMINATE ASSY
-4 OPP ~ SPAR INSTL





STAGGER INDEX
SCALE FULL



NOTES:

1. MANUFACTURE PER GR100B
2. TOLERANCES: (A) LAMINA THICKNESS TO BE .0050–.0055
   (B) MAXIMUM DEVIATION FROM INTENDED FIBER ORIENTATION SHALL NOT EXCEED 1°.
3. PART SHALL BE ULTRASONICALLY AND DIMENSIONALLY INSPECTED AFTER CURING, IN ADDITION ANY S/B FLAWS OR REGULARITY IN FIBER ORIENTATION SPACING, FINISH ETC, SHALL BE REPORTED. ALL RADII MUST BE RADIOGRAPHICALLY INSPECTED FOR VOIDS.
4. THIS CODE INDICATES THE TOTAL COMBINED NUMBER AND TYPE OF PLIES NOTED:

X
L-M-N

   X = TOTAL N° OF PLIES
   L = NO OF 0° PILES
   M = NO OF 90° PLIES
   N = NO OF 45° & 135° PLIES COMBINED
5. MACHINED EDGES SHALL BE FREE OF NOTCHES OR OTHER LOCALIZED IMPERFECTIONS.
6. EDGE OF TAPE PASSES THRU BASE POINT FOR 0°, 45°, 90°, AND 135° LAMINA WITH "0 STAGGER INDEX DOES NOT APPLY FOR LAMINA LESS THAN 3 N WIDE IN THE FILAMENT DIRECTION
7. OVERCOAT FASTENERS WITH SEALANT (GM 4107100) ON FUEL SIDE
8. COAT BOLTS SHANKS BEFORE INSTALLING WITH GM 4107300
9. APPLY – 19 (SEALANT) ALL AROUND CLIP FLANGE ADJACENT TO FRONT/ REAR SPAR
10. DIMENSIONS NOT SHOWN MAY BE SCALED
11. -1 and -2 ASSY TO BE INTEGRALLY CURED WITH D10B2010-1 (UPPER COVER).
12. MAKE FROM -1
13. MAKE FROM -2

FASTENER/RIVET CODE

CENTER HOLE DATA

F33615-77-C-3071

GRUMMAN AEROSPACE CORPORATION
BETHPAGE, NEW YORK 11714

INTERMEDIATE SPARS
ASSY AND INSTL

26512 D10B2012

SHEET 1 OF 2

The failure mode experienced was delamination in the flange bend radius. The flatwise tension allowable was obtained using a design reduction factor of 0.80 on average test values:

$$P_{allow.} = .80\ (546) = 437\ \text{lb/in.}$$

$$MS = \frac{437}{300} - 1 = +\,0.45\ \text{(delamination in bend radius)}$$

4.1.5 Central Rib Design - Graphite/Epoxy (Fig. 49)

The central rib is 24 ply graphite/epoxy laminate with a 4-8-12 ply orientation. The rib was designed to resist a 150 lb/in. flatwise tension load. The margin of safety was ample for all possible failure modes.

4.1.6 Lower Cover (Stitched) Design - Graphite/Epoxy (Fig. 50)

The lower cover is a 50 ply graphite/epoxy laminate with a 16-10-24 ply orientation. The stitched cap angles are a 26 ply graphite/epoxy laminate with a 2-4-20 ply orientation. The cap angles configuration and laminate stacking sequence is identical to those of Concept I (D10B2004-57). This configuration had an average failure load of 785 lb/in. when tested at 270°F (dry). The allowable flatwise tension load was obtained using a design reduction factor of 0.80 on average test values.

$$P_{allow.} = .80\ (785\ \text{lb/in.}) = 628\ \text{lb/in.} \quad \text{TEMP} = 270°\text{F (dry)}$$

$$MS = \frac{628}{300} - 1 = \text{ample (tension failure of stitch)}$$

Note that the above $P_{allow.}$ is for flatwise tension load acting alone, where as in the test box the stitched joint is under the following loading:

$N_x = 118$ lb/in.

$N_y = 118$ lb/in.

$N_z = 300$ lb/in.

$N_{xy} = 1200$ lb/in.

$M_{yy} = -199$ in.-lb/in.

Using the above loading, the critical MS are

MS = 0.97 (90° ply)
MS = 0.55 (45° ply)

TEMP = 270°F (dry)

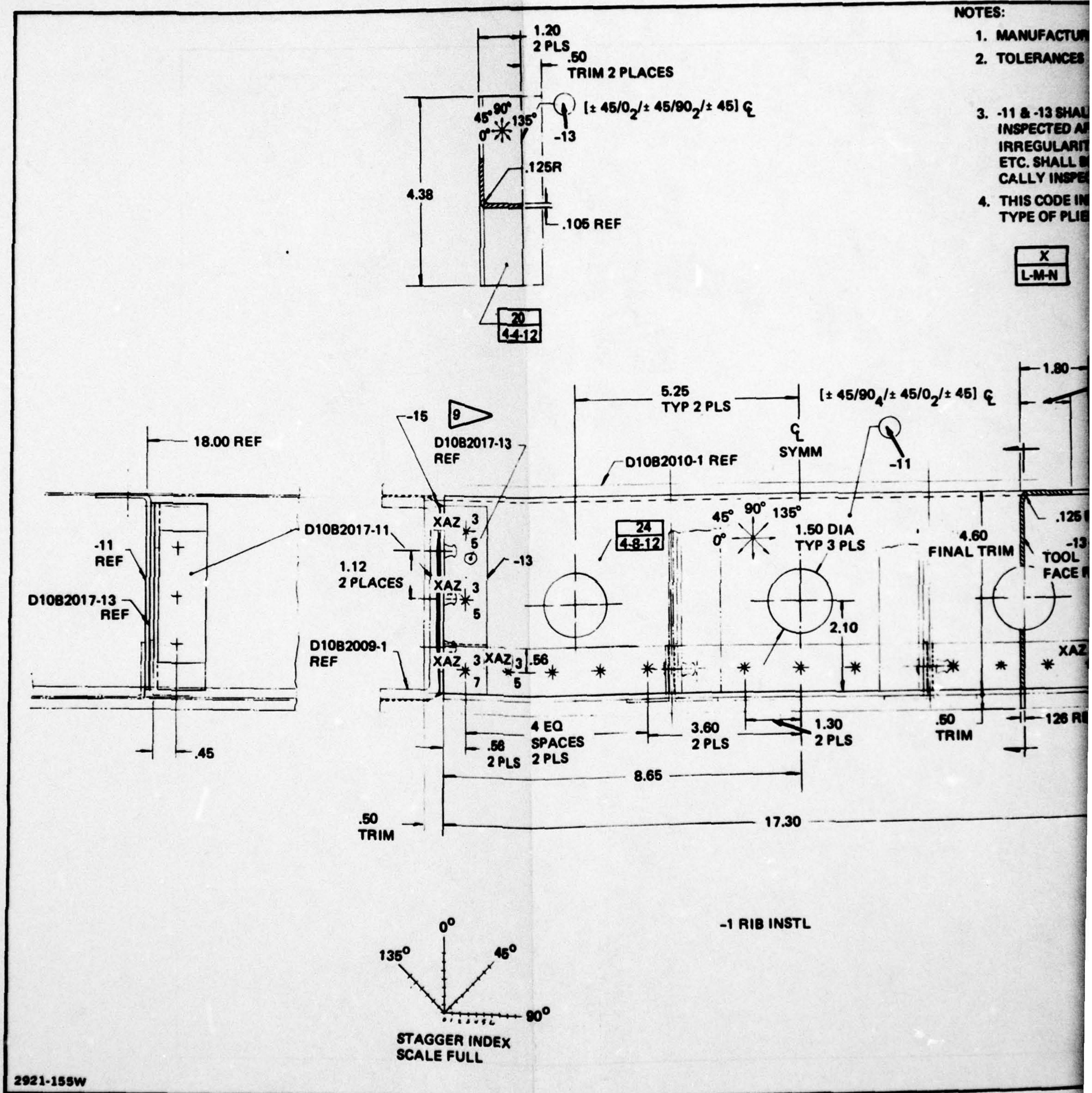


Fig. 49 Central Rib Assembly & Installation

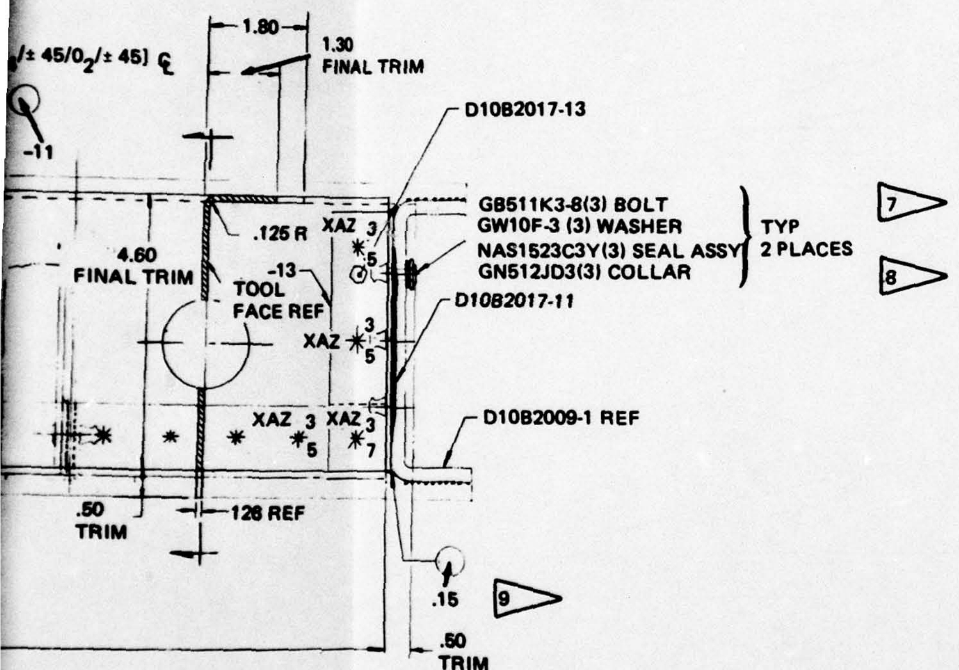
NOTES:

1. MANUFACTURE -11 PER GR100B
2. TOLERANCES (a) LAMINA THICKNESS TO BE .0050-.0055
   (b) MAXIMUM DEVIATION FROM INTENDED FIBER ORIENTATION SHALL NOT EXCEED 1°.
3. -11 & -13 SHALL BE ULTRASONICALLY AND DIMENSIONALLY INSPECTED AFTER CURING. IN ADDITION ANY FLAWS OR IRREGULARITY IN FIBER ORIENTATION, SPACING, FINISH, ETC. SHALL BE REPORTED ALL RADII MUST BE RADIOGRAPHICALLY INSPECTED FOR VOIDS.
4. THIS CODE INDICATES THE TOTAL COMBINED NUMBER AND TYPE OF PLIES NOTED:

X
L-M-N

X = TOTAL NO. OF PLIES
L = NO. OF 0° PLIES
M = NO. OF 90° PLIES
N = NO. OF 45° & 135° PLIES COMBINED

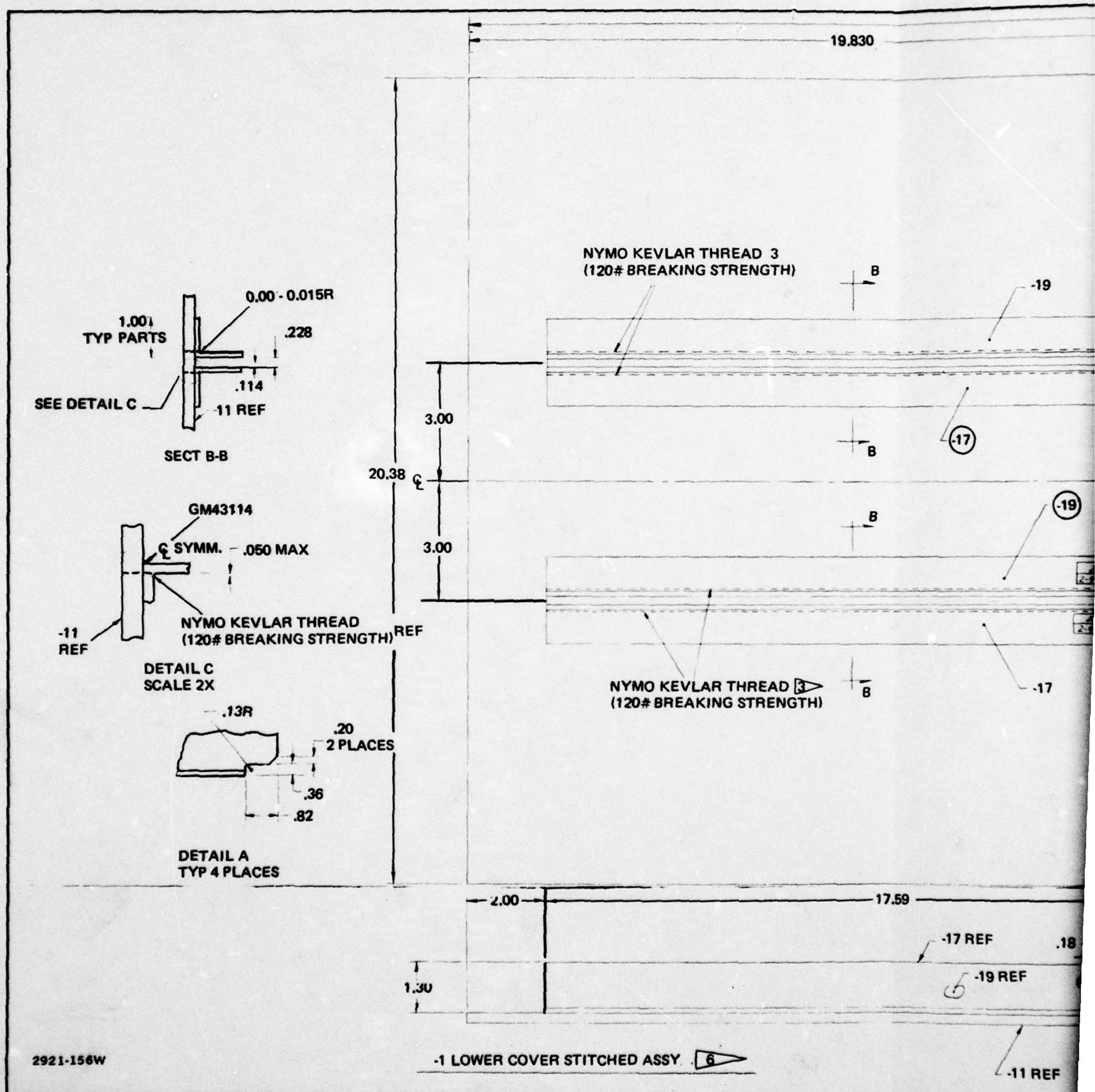
5. MACHINED EDGES SHALL BE FREE OF NOTCHES OR OTHER LOCALIZED IMPERFECTIONS.
6. EDGE OF TAPE PASSES THRU BASE POINT FOR 0°, 45°, 90° AND 135° LAMINA WITH "0" STAGGER INDEX. STAGGER INDEX DOES NOT APPLY FOR LAMINA LESS THAN 3 IN. WIDE IN THE FILAMENT DIRECTION.
7. OVERCOAT FASTENERS WITH SEALANT (GM4107100) ON FUEL SIDE.
8. COAT BOLTS SHANKS BEFORE INSTALLING WITH GM4107300.
9. APPLY -15 (SEALANT) ALL AROUND CLIP FLANGE ADJACENT TO FRONT/REAR SPAR.
10. DIMENSIONS NOT SHOWN MAY BE SCALED.

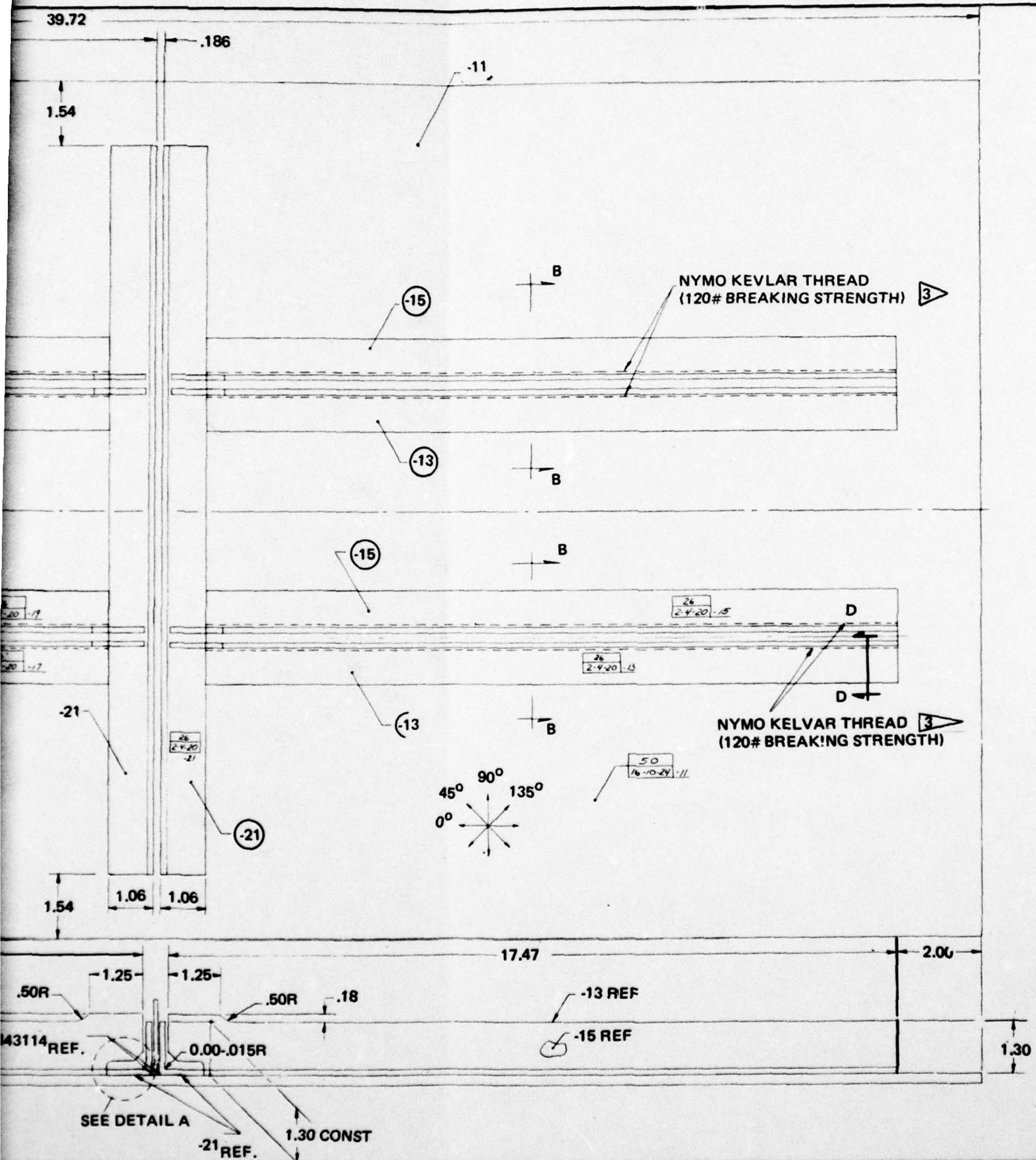


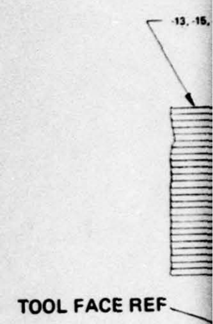
CONTRACT NO. F33615-77-C-3071

CENTRAL RIB ASSY AND INSTL

26512 D10B2013

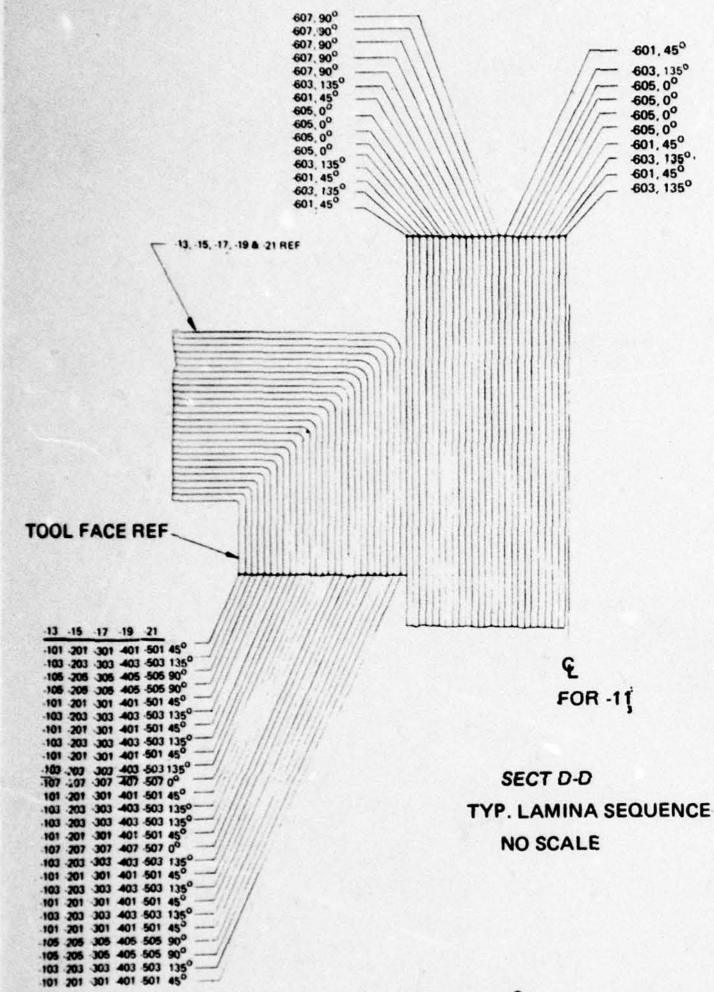

19.830
NYMO KEVLAR THREAD 3
(120# BREAKING STRENGTH)
B
-19
0.00 - 0.015R
1.00
TYP PARTS
.228
.114
SEE DETAIL C
-11 REF
SECT B-B
3.00
-17
20.38
-19
GM43114
SYMM.
.050 MAX
3.00
-11
REF
NYMO KEVLAR THREAD
(120# BREAKING STRENGTH)
REF
DETAIL C
SCALE 2X
NYMO KEVLAR THREAD 3
(120# BREAKING STRENGTH)
-17
.13R
.20
2 PLACES
.36
.82
DETAIL A
TYP 4 PLACES
2.00
17.59
-17 REF
.18
-19 REF
1.30
2921-156W
-1 LOWER COVER STITCHED ASSY 6
-11 REF



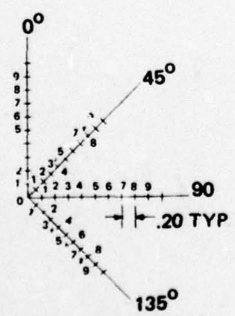


-13	-15	-17	-19	-21	
-101	-201	-301	-401	-501	45°
-103	-203	-303	-403	-503	135°
-105	-205	-305	-405	-505	90°
-105	-205	-305	-405	-505	90°
-101	-201	-301	-401	-501	45°
-103	-203	-303	-403	-503	135°
-101	-201	-301	-401	-501	45°
-103	-203	-303	-403	-503	135°
-101	-201	-301	-401	-501	45°
-103	-203	-303	-403	-503	135°
-107	-207	-307	-407	-507	0°
101	-201	-301	-401	-501	45°
-103	-203	-303	-403	-503	135°
-103	-203	-303	-403	-503	135°
-101	-201	-301	-401	-501	45°
-107	207	-307	407	507	0°
-103	-203	-303	-403	-503	135°
-101	-201	-301	-401	-501	45°
-103	-203	-303	-403	-503	135°
-101	-201	-301	-401	-501	45°
-103	-203	-303	-403	-503	135°
-101	-201	-301	-401	-501	45°
-105	205	-305	-405	-505	90°
-105	-205	-305	-405	-505	90°
-103	-203	-303	-403	-503	135°
-101	-201	-301	-401	-501	45°

2



SECT D-D
TYP. LAMINA SEQUENCE
NO SCALE



STAGGER INDEX

NOTES:

1. MANUFACTURE SPECIMEN PER GR-100B
2. TOLERANCES (NOT TO BE ACCUMULATED)
   A' LAMINA THICKNESS TO BE .0050-.0055
   B. MAXIMUM DEVIATION FROM INTENDED FIBER ORIENTATION SHALL NOT EXCEED 1°
3. STITCH USING A CHAMPION NEEDLE. STITCH PITCH TO BE APPROXIMATELY FOUR PER INCH. COAT THREAD BEFORE STITCHING USING EPON 828 RESIN
4. $\boxed{\begin{array}{c} X \\ L\text{-}M\text{-}N \end{array}}$ THIS CODE INDICATES THE TOTAL COMBINED NUMBER AND TYPE OF PLIES NOTED.
   X = TOTAL NUMBER OF PLIES
   L = NUMBER OF 0° PLIES
   M = NUMBER OF 90° PLIES
   N = NUMBER OF 45° & 135° PLIES COMBINED
5. EDGE OF TAPE PASSES THUR BASE POINT 0°, 45°, 90° AND 135° LAMINA WITH "O" STAGGER INDEX. STAGGER INDEX DOES NOT APPLY FOR LAMINA LESS THAN 3 INCH WIDE IN THE FILAMENT DIRECTION.
6. DIMENSIONS SHOWN ARE NET TRIM

FOR PARTS LIST, USAGE DATA, AND DWG SH STATUS, SEE DOCUMENT SAME NUMBER PREFIXED PL

UNLESS OTHERWISE SPECIFIED DIMENSIONS IN INCHES LINEAR TOL XX ±.03; XXX ±.010 ANGULAR TOL ±0°30' TOL ON LOFTED DELINEATIONS IS	CONTRACT NO. F33615-71 C 3071	GRUMMAN AEROSPACE CORPORATION BETHPAGE, NEW YORK 11714
STRESS 4/4/78 TOOLING 4/11/78 M&P 4/11/78 Q.C.	DRAWN BY MR 28 FEB 78 LAYOUT BY CGN 16 FEB 78 CHECKED BY GR LEADER REL GROUP PROJ ENGR GOVT APPD	LOWER COVER STITCHED ASSY SIZE; CODE IDENT NO. 26512; D10B2014 SCALE Full / None; SHEET 1 OF 3

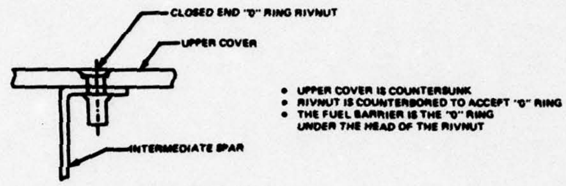
Fig. 50 Lower Cover Stitched Assembly

4.1.7 Test Box Assembly (Fig. 51)

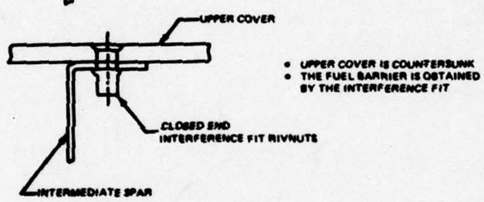
The mechanical fasteners used to assemble the test box and their corresponding allowable are listed in Table 10.

The Test Box Assembly contains four distinct types of spar fuel sealing concepts three of which are representative of interior spars and one representative of the front and rear spars. The interior spar fuel sealing concepts are as follows:

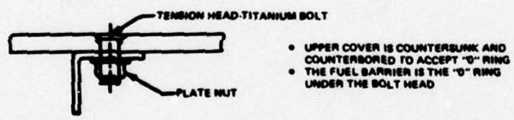
TYPE A



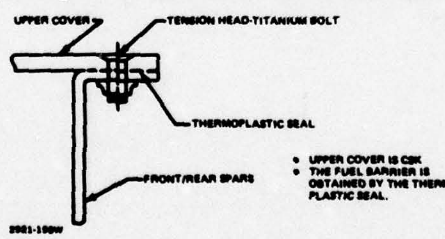
TYPE B



TYPE C



The fuel sealing concept representative of the front and rear spars is as follows:



These fuel sealing concepts will be subjected to the loadings described in Section VI.

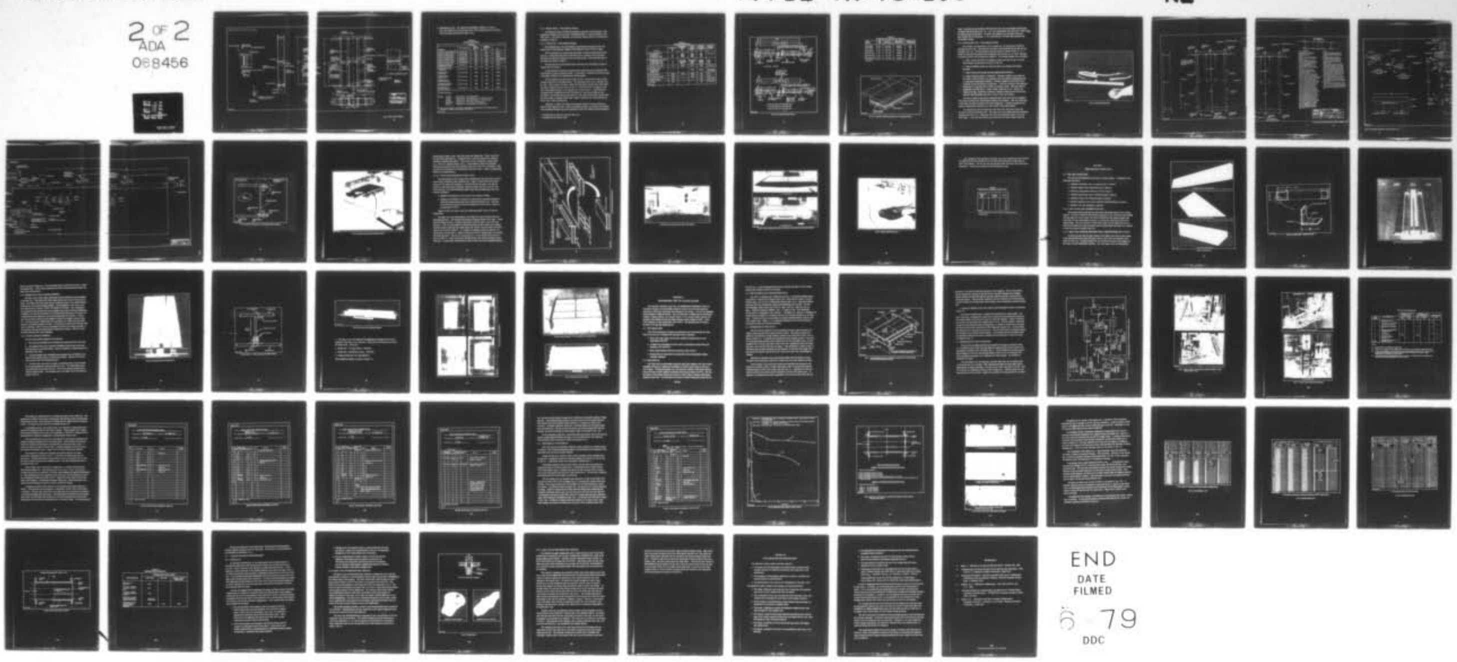
4.2 THERMOPLASTIC SEALING

The thermoplastic sealing phase of the program consisted of three parts:

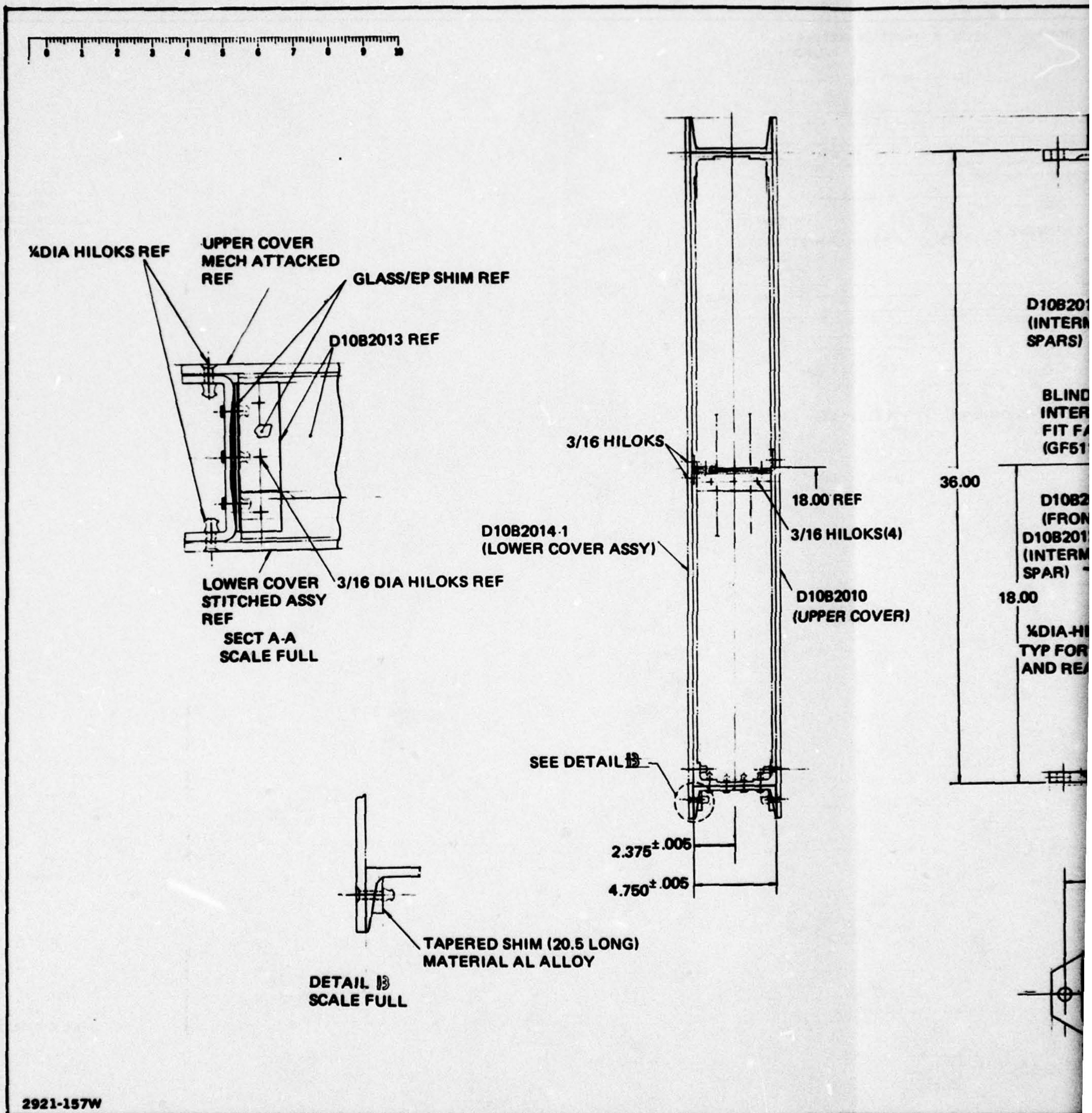
- Industry survey of available thermoplastic adhesives
- Element test of candidate materials and development of upper cover removal and reassembly procedures

AD-A068 456 GRUMMAN AEROSPACE CORP BETHPAGE N Y F/G 1/3
ADVANCED COMPOSITE WING COVER-TO-SUBSTRUCTURE ATTACHMNET (CTSA)--ETC(U)
JAN 79 C CACHO-NEGRETE, H FORSCH, G CONCANNON F33615-77-C-3071
UNCLASSIFIED AFFDL-TR-78-190 NL

2 OF 2
ADA
068456



END
DATE
FILMED
6-79
DDC



¼DIA HILOKS REF
UPPER COVER
MECH ATTACKED
REF
GLASS/EP SHIM REF
D10B2013 REF
LOWER COVER
STITCHED ASSY
REF
3/16 DIA HILOKS REF
SECT A-A
SCALE FULL
3/16 HILOKS
18.00 REF
3/16 HILOKS(4)
D10B2014-1
(LOWER COVER ASSY)
D10B2010
(UPPER COVER)
SEE DETAIL B
2.375±.005
4.750±.005
TAPERED SHIM (20.5 LONG)
MATERIAL AL ALLOY
DETAIL B
SCALE FULL
36.00
18.00
D10B201
(INTERM
SPARS)
BLIND
INTER
FIT FA
(GF51
D10B2
(FRON
D10B201
(INTERM
SPAR)
¼DIA-HI
TYP FOR
AND REA

2921-157W

/

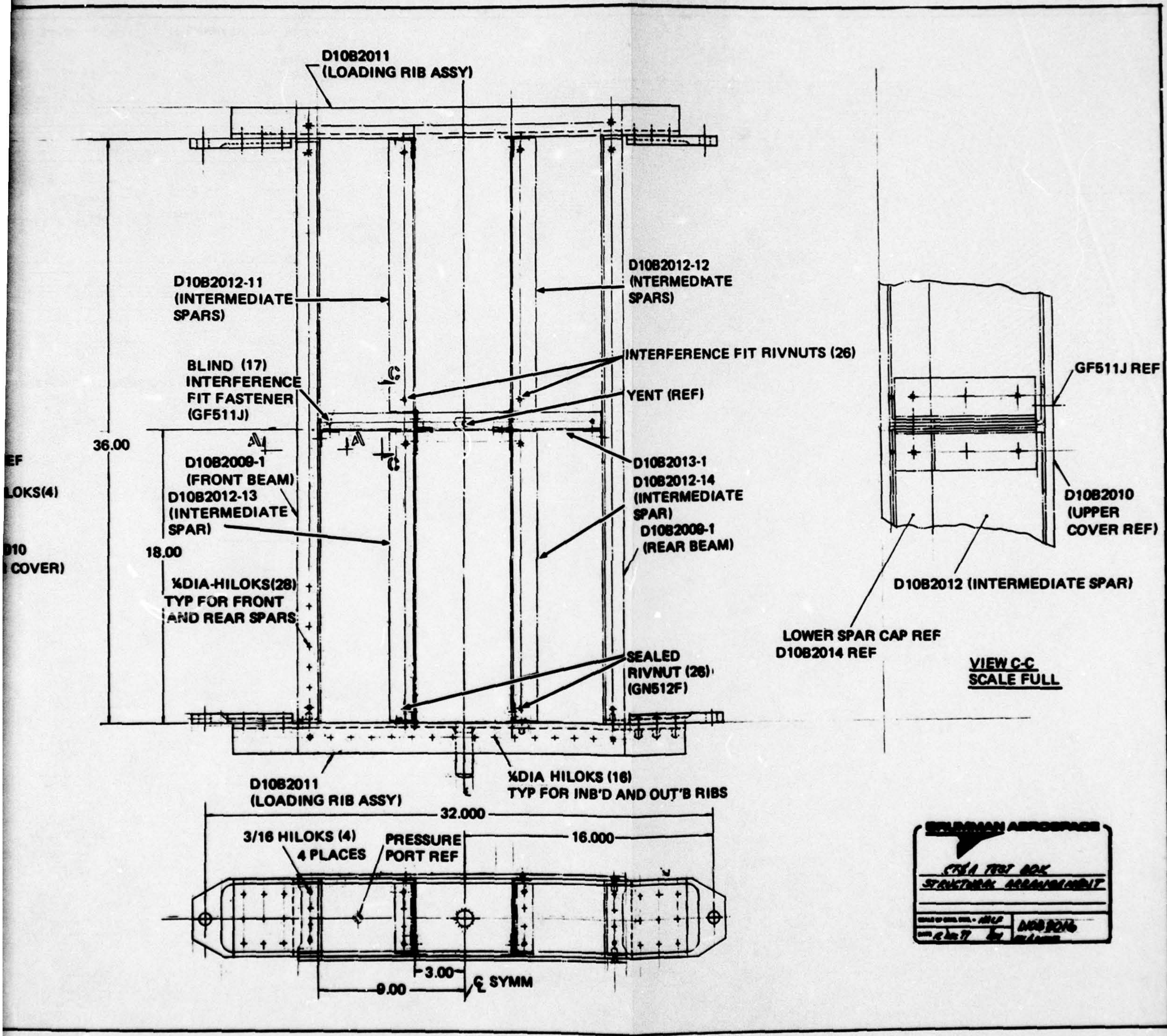


Fig. 51 CTSA Test Box Assembly

- **Subcomponent Test - the selected thermoplastic adhesive is used to seal a fuel tight box and the demonstration of the disassembly and reassembly of the thermoplastically sealed upper cover.**

TABLE 10
TEST BOX HARDWARE

	FASTENER			
LOCATION	TYPE (QUANTITY)	SHEAR STRENGTH (LB)	TENSION STRENGTH (LB)	MS
COVER TO FRONT/REAR SPAR	GB 510F4 (104)	4650	5820	AMPLE
COVER TO LOADING RIBS	GB 510F4 (64)	4650	5820	AMPLE
COVER TO INTERM. SPARS	GN 512F3 (24)	2633	2315	AMPLE
COVER TO INTERM. SPARS	C2R1868 (26)	1850*	1190*	+.80 (TENSION)
COVER TO INTERM. SPARS	MS90353-08(3)**	5900	3650	AMPLE
COVER TO CENTRAL RIB INTERMEDIATE SPARS	GB 510F4 (6)	4650	5820	AMPLE
FRONT/REAR SPAR TO LOADING RIB	GB 511K3 (12)	2690	2500	AMPLE
INTERM. SPAR TO LOADING RIB	GB 511K3 (28)	2690	2500	AMPLE
INTERM. SPAR TO CENTRAL RIB	GB 511K3 (16)	2690	2500	AMPLE
CENTRAL RIB TO FRONT/REAR SPAR	GB 511K3 (12)	2690	2500	AMPLE
INTERM. SPAR WEB TO STITCHED SPAR CAP	GB 511K3 (56)	2690	2500	AMPLE
CENTRAL RIB TO STITCHED SPAR CAP	GB 511K3 (11)	2690	2500	AMPLE

*WITHOUT CORE BOLT

WHERE:
GB 510F4 = 0.250 INCH DIA – CSK TITANIUM BOLT
GN 512F3 = 0.250 INCH DIA – CSK CLOSED END – "O" RING STEEL RIVNUT
C2R1868 = 0.281 INCH DIA – CSK INTERFERENCE FIT – STEEL RIVNUT
MS90353-08** = 0.260 INCH DIA – CSK – STEEL HUCK BLIND BOLT
GB 511K3 = 0.189 INCH DIA – PROTRUDING HD TITANIUM HI-LOK

**SUBSTITUTE FASTENER – THIS TYPE OF FASTENER WAS USED BECAUSE OF THE UNAVAILABILITY OF GN512F3 – RIVNUT IN THE REQUIRED GRIP LENGTH.

2921-158W

4.2.1 Industry Survey - Thermoplastic Sealing

An assessment of the available thermoplastic materials was performed. This assessment resulted in the selection of Polyethersulphone*, Versalon 1200D**, and TPX-1015**. For further evaluation, the materials and data that were evaluated are presented in Table 11.

4.2.2 Element Test - Thermoplastic Sealing

Six specimens (Fig. 52) were bonded by translaminate heating with the melt temperature for the polyether-sulphone (PES) adhesive in the 575-600°F range.

Three specimens were heated from both sides, and three specimens from one side only. During the heat-up part of the bond cycle, a pressure of 11.0 psi was maintained for the first 5 minutes of the cool-down period. Test results for the six specimens are shown in Table 12.

All failures were in the graphite/epoxy adherends; the PES adhesive bonds remained intact in all tests.

A non-destructive inspection of bonded and unbonded specimens indicated local delaminations at various laminate depths. At this point, a program decision was made to terminate bonding by the translaminate heating method.

Trial specimens were fabricated using a 0.25 in. wide strip of 0.002 in. thick stainless steel foil as a heating element. The specimens were 3.0 in. long and 1.20 in. wide. Three layers of 0.004 in. thick PES were placed on both sides of the stainless steel heating element as shown in Fig. 53. Electrical power was applied to the ends of the heating element to the capacity of 8.0 amps at 20.0 v. Insufficient heat was generated to completely melt the PES adhesive - only local melting in close proximity to the heating element was achieved - and it was obvious that complete melting would require a heating element with a higher resistivity and a thermoplastic adhesive with a lower melting point.

Therefore, a family of candidate thermoplastic adhesive resins produced by General Mills Chemicals, Inc., under the registered names of Versalon and TPX1015 were considered because they showed promise of use in the required melt temperature

* manufactured by Imperial Chemical Industries

** manufactured by General Mills

TABLE 11
CANDIDATE MATERIALS

PLASTIC	ELONGATION (%) RT	COMPRESSIVE STRENGTH (PSI) RT	FLEXURAL YIELD STRENGTH (PSI)	RESISTANCE TO HEAT (CONTINUOUS) (°F)	EFFECT OF ORGANIC *SOLVENTS*
1. POLY (AMIDE-IMIDE)					
(A) UNFILLED	2.5	35000	23400	550	EXCELLENT
(B) MINERAL FILLED	2.1	46700	21500	550	
(C) GRAPHITE FILLED	2.5	33860	22100	550	
2. THERMOPLASTIC POLYESTER					
(A) 18% GLASS FILLED	2-3	16200-18000	26000-26500	200-300	FAIR
(B) 30 % GLASS FILLED	2-4	18000-23500	26000	240-350	FAIR
(C) 36% GLASS FILLED	2	30000	38000	200-300	FAIR
3. AROMATIC POLYESTER	7.9	20000	1500	550	EXCELLENT
4. POLY-PHENYLENE SULFIDES - 40% GLASS FILLED	3	–	37000	400-500	EXCELLENT BELOW 400°F
5. POLYSULPHONE	50-100	13900	15400	300	FAIR
6. POLYETHERSULPHONE	30-80	–	18650	325	FAIR
7. VERSALON 1200D	400	–	–	396	EXCELLENT
8. TPX-1015	400	–	–	396	EXCELLENT

2921-160W

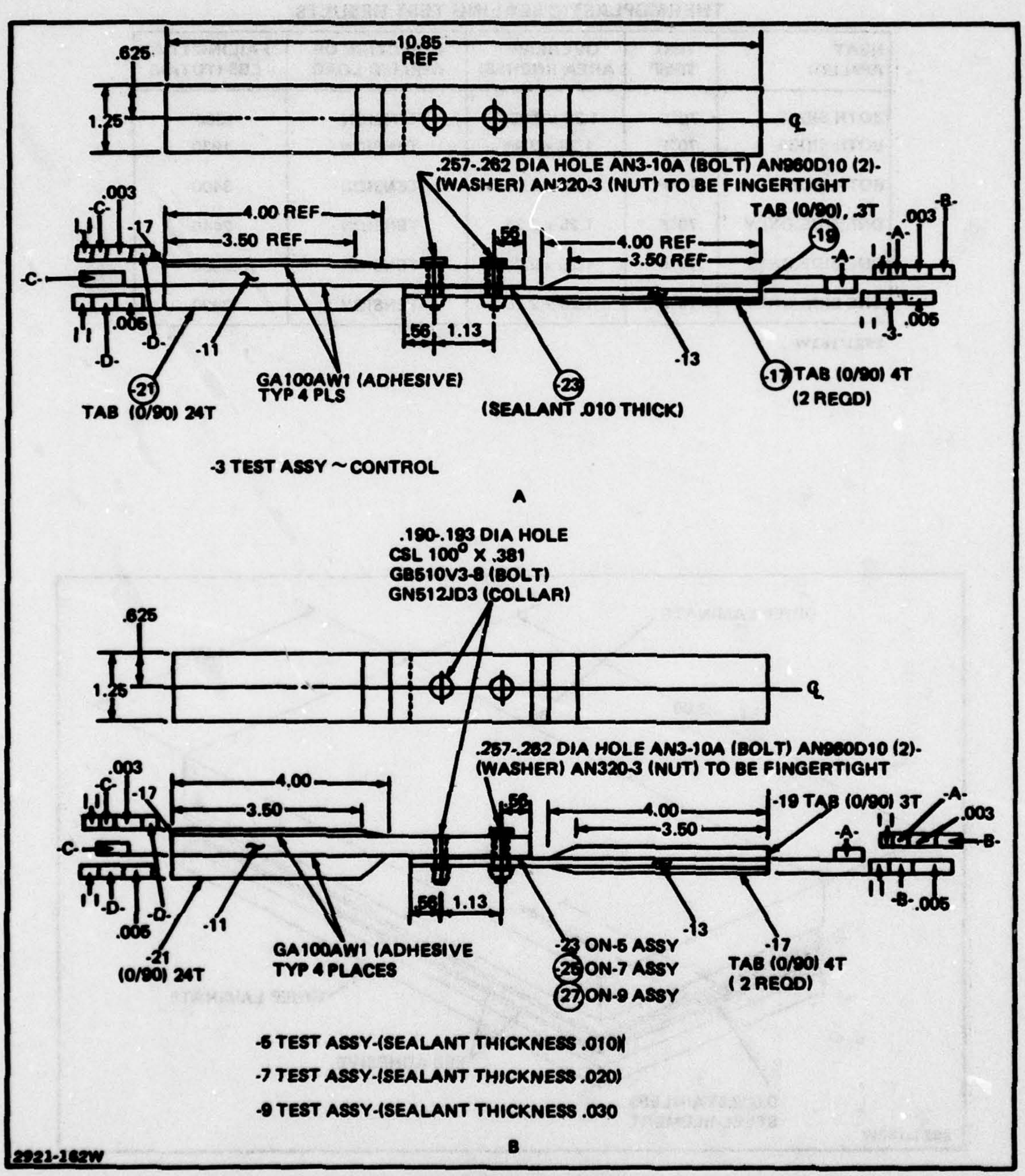


Fig. 52 Thermoplastic Sealing, Element

TABLE 12
THERMOPLASTIC SEALING TEST RESULTS

HEAT APPLIED	TEST TEMP	OVERLAP AREA (INCHES)	DIRECTION OF APPLIED LOAD	FAILING LOAD LBS (TOTAL)
BOTH SIDES	70°F	1.25 x 2.25	TENSION	1300
BOTH SIDES	70°F	1.25 x 2.25	TENSION	1930
BOTH SIDES	70°F	1.25 x 2.25	TENSION	3400
ONE SIDE ONLY	70°F	1.25 x 2.25	TENSION	2440
ONE SIDE ONLY	70°F	1.25 x 2.25	TENSION	2860
ONE SIDE ONLY	70°F	1.25 x 2.25	TENSION	2920

2921-161W

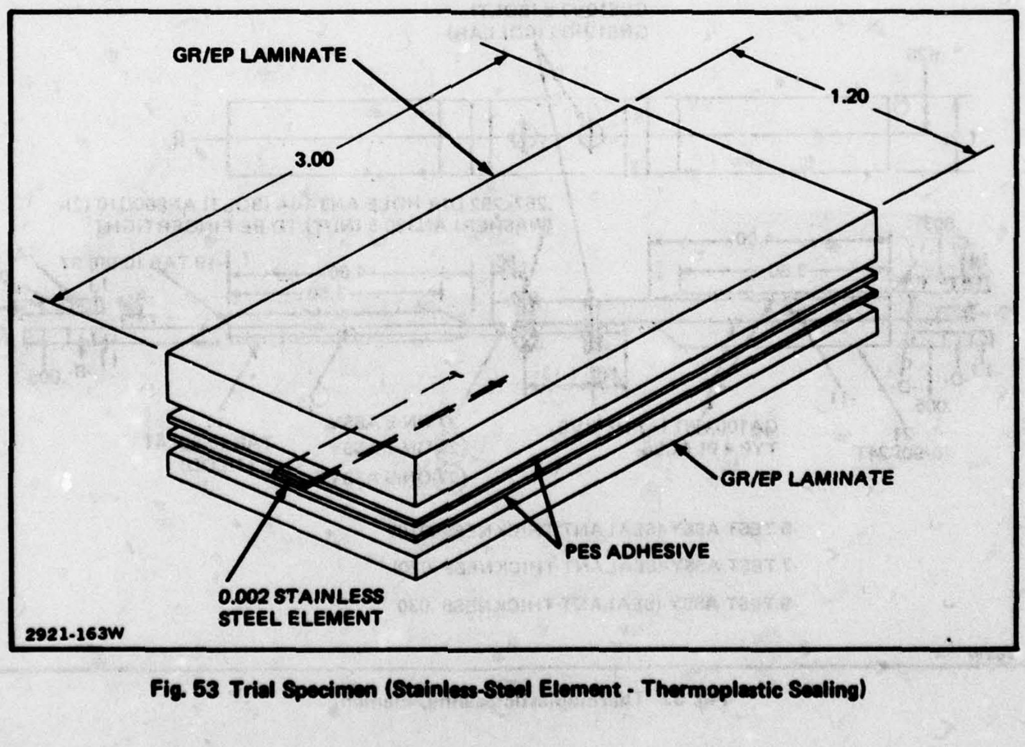


Fig. 53 Trial Specimen (Stainless-Steel Element - Thermoplastic Sealing)

range. Specimens using Versalon 1200D and TPX 1015 were successfully bonded using a graphite healing element (Fig. 54). The melt temperature was in the 420 - 479°F range, the softening point being 392°F. At 470°F, the adhesive was very fluid and flowed from between the two adherends. A 37.0 inch long by 1-5/8 inch wide specimen was successfully bonded.

4.2.3 Subcomponent Test - Thermoplastic Sealing

Due to better low temperature (-67°F) properties, the thermoplastic adhesive selected was TPX 1015. This adhesive was used to thermoplastically seal the test box assembly (Fig. 55). The thermoplastic seal test section is shown in Fig. 56. It should be noted that the fastener/nut combination does not have an "O" ring. The seal is achieved solely by the thermoplastic adhesive. The sealing sequence was as follows:

1. Bond -21 and -33 (TPX 1015 sealant) to both covers and -27 and -31 (TPX 1015 sealant) to substructure as shown in Fig. 55.

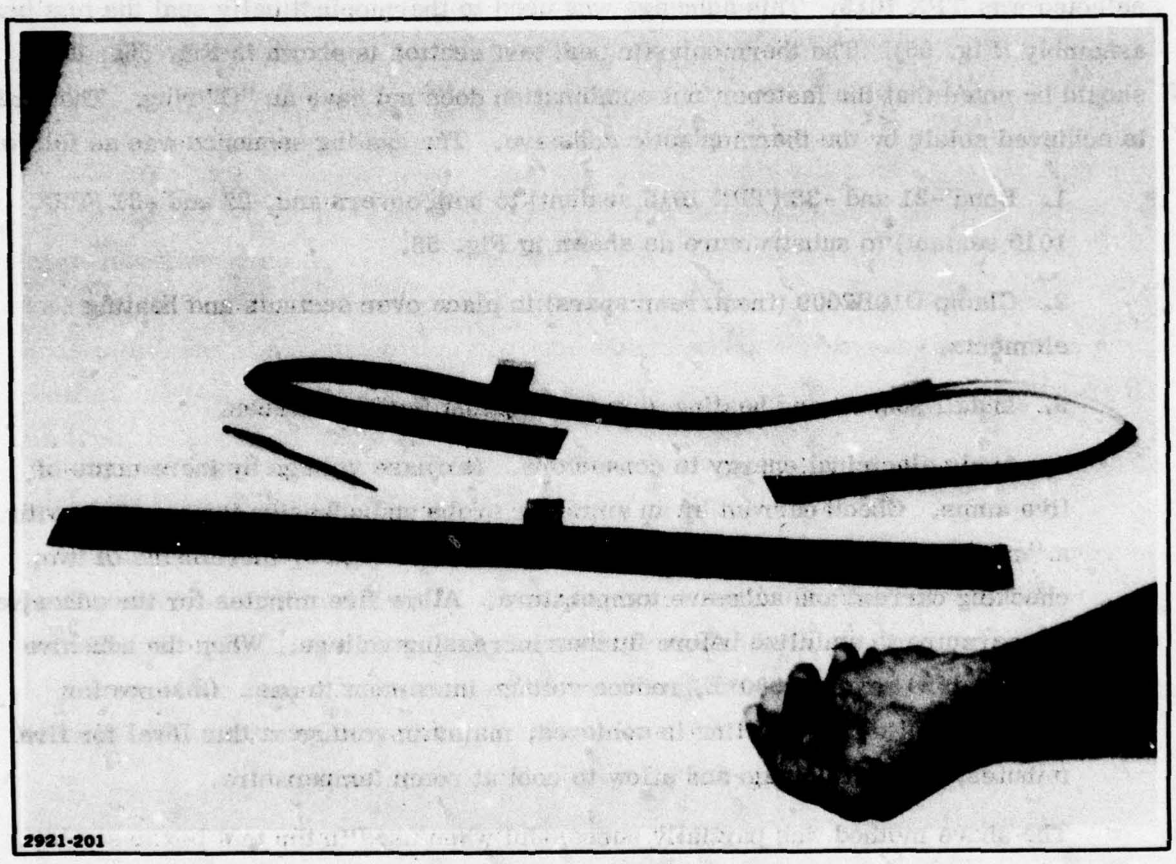
2. Clamp D10B2009 (front/rear spars) in place over sealants and heating elements.

3. Install sealant and heating elements against faying surfaces.

4. Apply electrical energy to connectors. Increase voltage by increments of five amps. Check current by an ammeter probe and adhesive temperature with a "mini-mite" temperature indicator. Increase voltage by increments of two, checking current and adhesive temperature. Allow five minutes for the adhesive temperature to stabilize before further increasing voltage. When the adhesive temperature reaches 380°F, reduce voltage increment to one. Observe for signs of melting. If melting is achieved, maintain voltage at this level for five minutes, turn off voltage and allow to cool at room temperature.

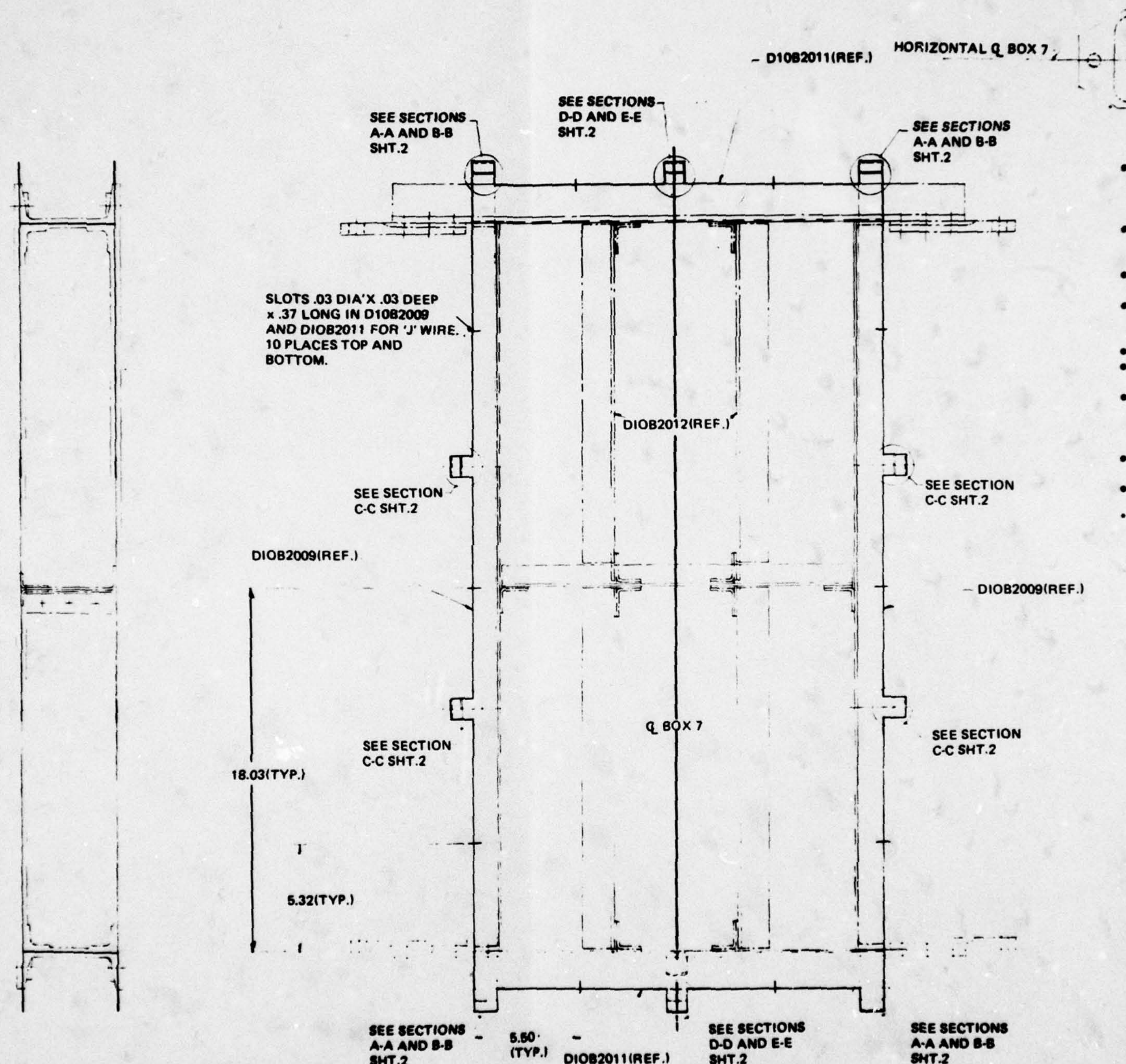
The above method was partially successful when used in the test box assembly. Only partial melting of the thermoplastic adhesive was obtained. This was mainly due to the large heat sink presented by the steel loading ribs. Complete melting was obtained by inserting the assembly in an oven at 400°F for twenty minutes.

To minimize the loss of energy due to the steel ribs, they were coated with two layers of the thermoplastic seal. The upper cover was bonded using the resistance heating method (Fig. 57). Inspection of the bond was performed using a 0.001 inch feeler gage. A one inch long disbond was discovered at all four corners of the box



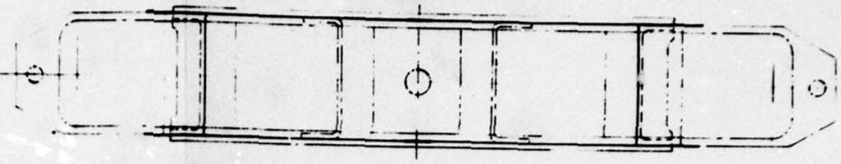
2921-201

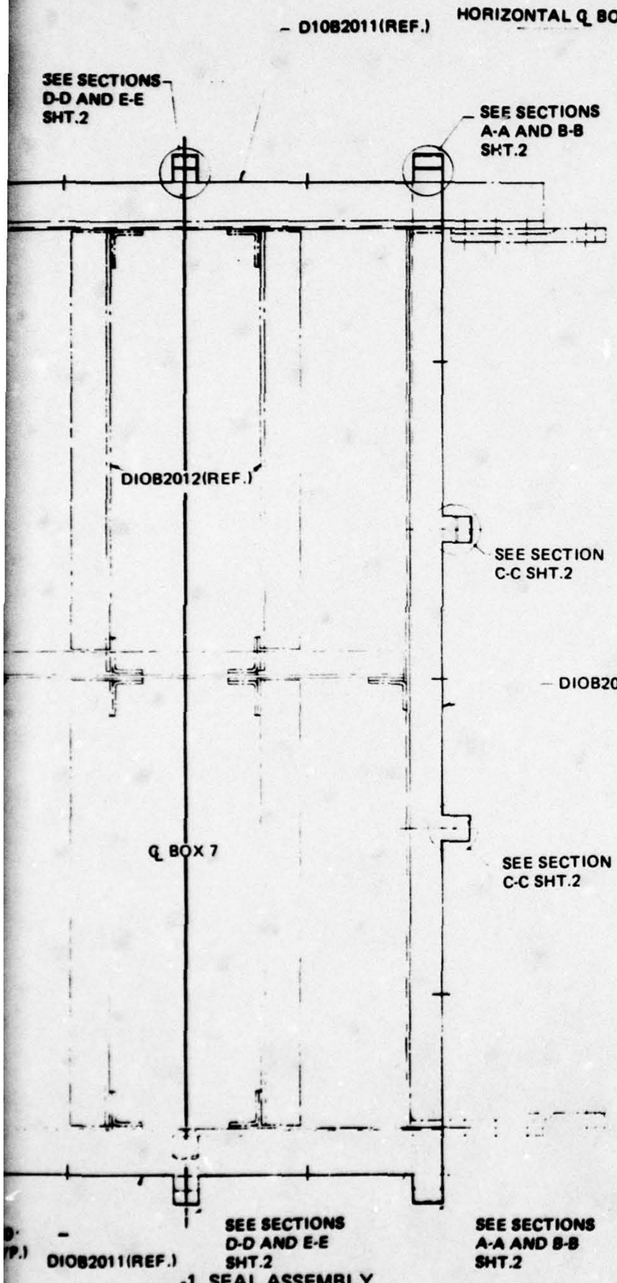
Fig. 54 Graphite Heating Element



-1, SEAL ASSEMBLY
VIEW LOOKING DOWN

2521-164W





SEALING SEQUENCE:-

- SOLVENT BOND -21, -33 TO BOTH COVERS AND -27, -31 TO SUB-STRUCTURE AS SHOWN ON SHT.2
- INSTALL -23, -25, -35, -47 SEALANTS AND -11, -15 HEATING ELEMENTS ON DIOB2014.
- CLAMP DIOB2009 IN PLACE OVER SEALANTS AND HEATING ELEMENTS.
- INSTALL -25, -29, -39 ADHESIVES AND -13 HEATING ELEMENTS AGAINST DIOB2014 AND DIOB2009.
- CLAMP DIOB2011 AGAINST DIOB2009.
- MAKE ELECTRICAL CONNECTOR TABS AS NOTE 4.
- APPLY ELECTRICAL ENERGY TO CONNECTORS AT FOUR CORNERS, (SECTIONS A-A AND B-B) AND BOND DIOB2009 TO DIOB2011.*
- MECHANICALLY ATTACH MID BEAMS DIOB2012 TO CLOSURE RIBS DIOB2011.
- AFTER COMPLETION OF SUBSTRUCTURE ASSEMBLY INSTALL UPPER COVER DIOB2010.
- APPLY ELECTRICAL ENERGY SUCCESSIVELY TO TWO ADJACENT CONNECTIONS. INCREASE VOLTAGE BY INCREMENTS OF FIVE UNTIL THE VARIAC DIAL REGISTERS 15. CHECK THE AMPERAGE BY AN AMP PROBE AND ADHESIVE TEMPERATURE WITH A "MINI MITE" TEMPERATURE INDICATOR. CONTINUE TO INCREASE VOLTAGE BY INCREMENTS OF TWO, CHECKING AMPERAGE AND ADHESIVE TEMPERATURE. ALLOW FIVE MINUTES FOR THE ADHESIVE TEMPERATURE TO STABILIZE BEFORE FURTHER INCREASING VOLTAGE. WHEN THE ADHESIVE TEMPERATURE REACHES 380°F., REDUCE VOLTAGE INCREMENT TO ONE, THE TEMPERATURE STABILIZATION PERIOD TO REMAIN AT FIVE MINUTES. AFTER THE ADHESIVE TEMPERATURE EXCEEDS 380°F. OBSERVE FOR SIGNS OF MELTING, AND IF MELTING IS ACHIEVED, MAINTAIN VOLTAGE AT THIS LEVEL. IF NO ADHESIVE FLOW IS OBSERVED, INCREASE VOLTAGE INCREMENTALLY UNTIL ADHESIVE TEMPERATURE REACHES 400°F. COOL DOWN PART OF SEALING CYCLE TO BE A RATE OF 2°F. PER MINUTE.

NOTES:-

1. TO PREVENT ELECTRICAL SHORTING DURING THE SEALING PROCESS ALL LAYERS OF ADHESIVE FILM MUST BE BUTTED.
2. NO LOOSE STRANDS OF GRAPHITE ALLOWED BEYOND THE PERIMETERS OF -11, -13 AND -15 HEATING ELEMENTS. TRIM TRANSVERSE FIBERS TO WITHIN PERIMETER OF ADHESIVE CARRIER FILM.
3. GRAPHITE CLOTH HEATING ELEMENTS TO BE SOLVENT BONDED TO ONE LAYER OF ADHESIVE FILM AND HEATED UNDER PRESSURE TO IMPREGNATE THE FABRIC.
4. APPLY SILVER BASE EPOXY CONDUCTIVE PASTE -45 TO ENDS OF GRAPHITE CLOTH HEATING ELEMENTS AS SHOWN. CLEAN EXCESS PASTE FROM OUTSIDE SURFACES OF HEATING ELEMENT TO PREVENT ELECTRICAL ARCING. ALLOW -45 TO CURE AT ROOM TEMPERATURE FOR 24 HOURS.
5. PRIOR TO INSTALLATION OF -11, -13 AND -15 HEATING ELEMENTS. THE RESISTIVITY OF A REPRESENTATIVE 12.0 INCH LENGTH OF GRAPHITE CLOTH SHOULD BE CHECKED, AND A MINIMUM RESISTANCE OF 2.0 OHMS REGISTERED.
6. TO STIFFEN ELECTRICAL CONNECTIONS AND TO PREVENT ARCING DURING THE SEALING CYCLE, A 2.0" x 60" x .05 (APPROX) GR/EP OR GR/PI LAMINATE IS TO BE CLAMPED BETWEEN THE METAL CONNECTORS AND THE C.S.T.A. BOX.

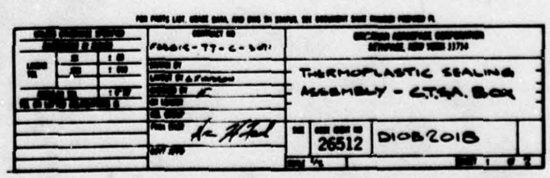


Fig. 55 Thermoplastic Sealing Assy CTSA Box (Sheet 1 of 2)

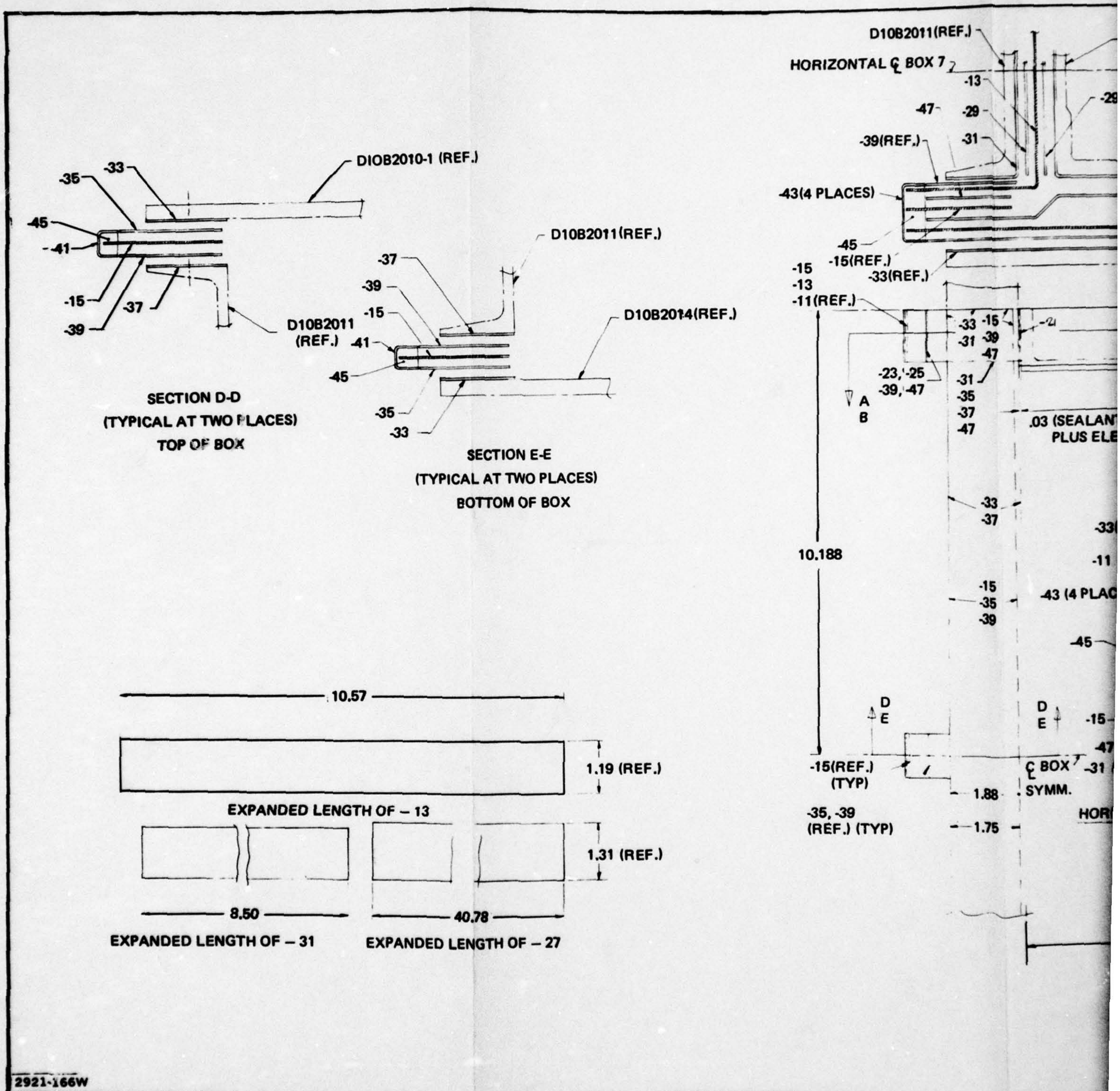
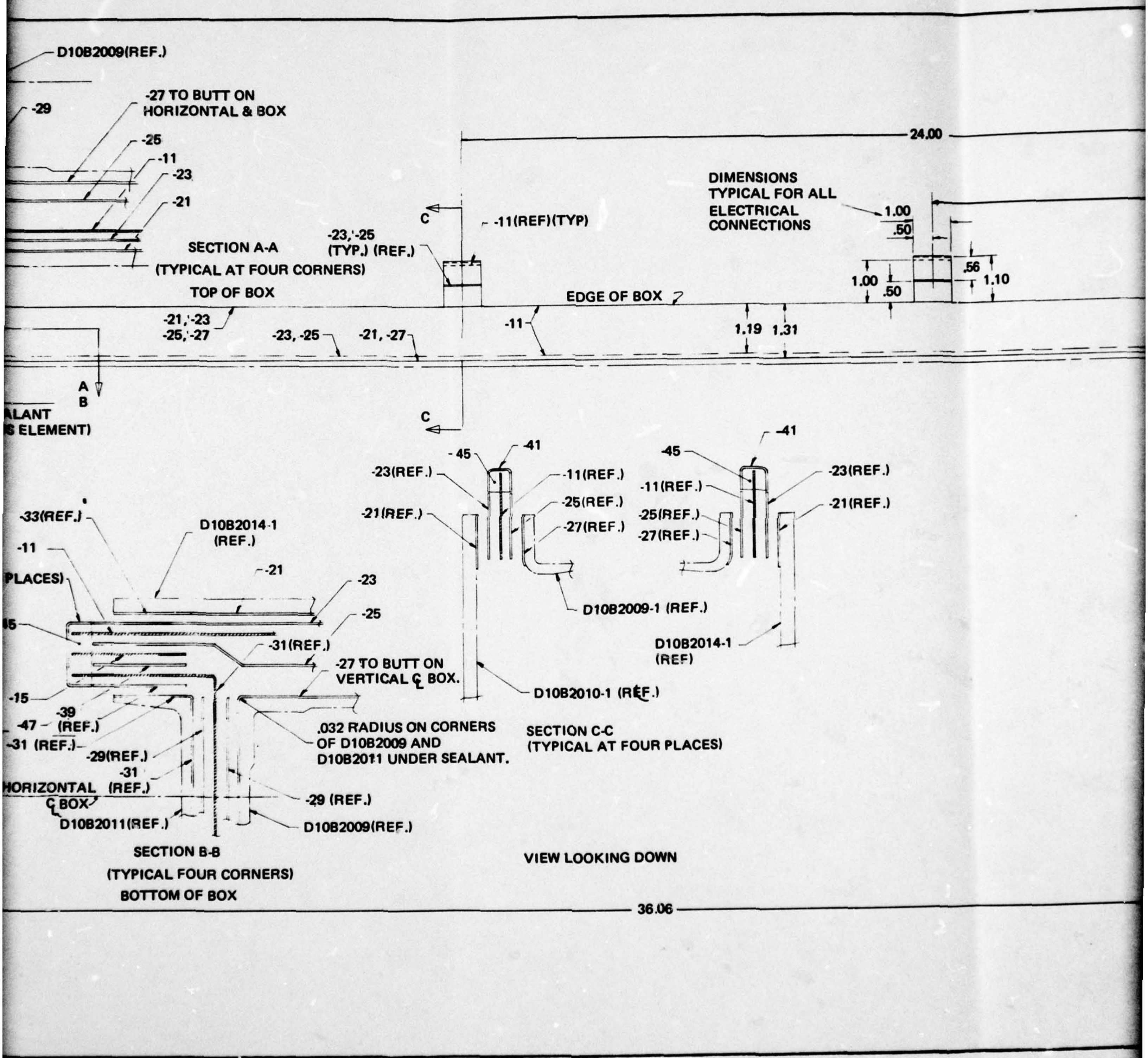
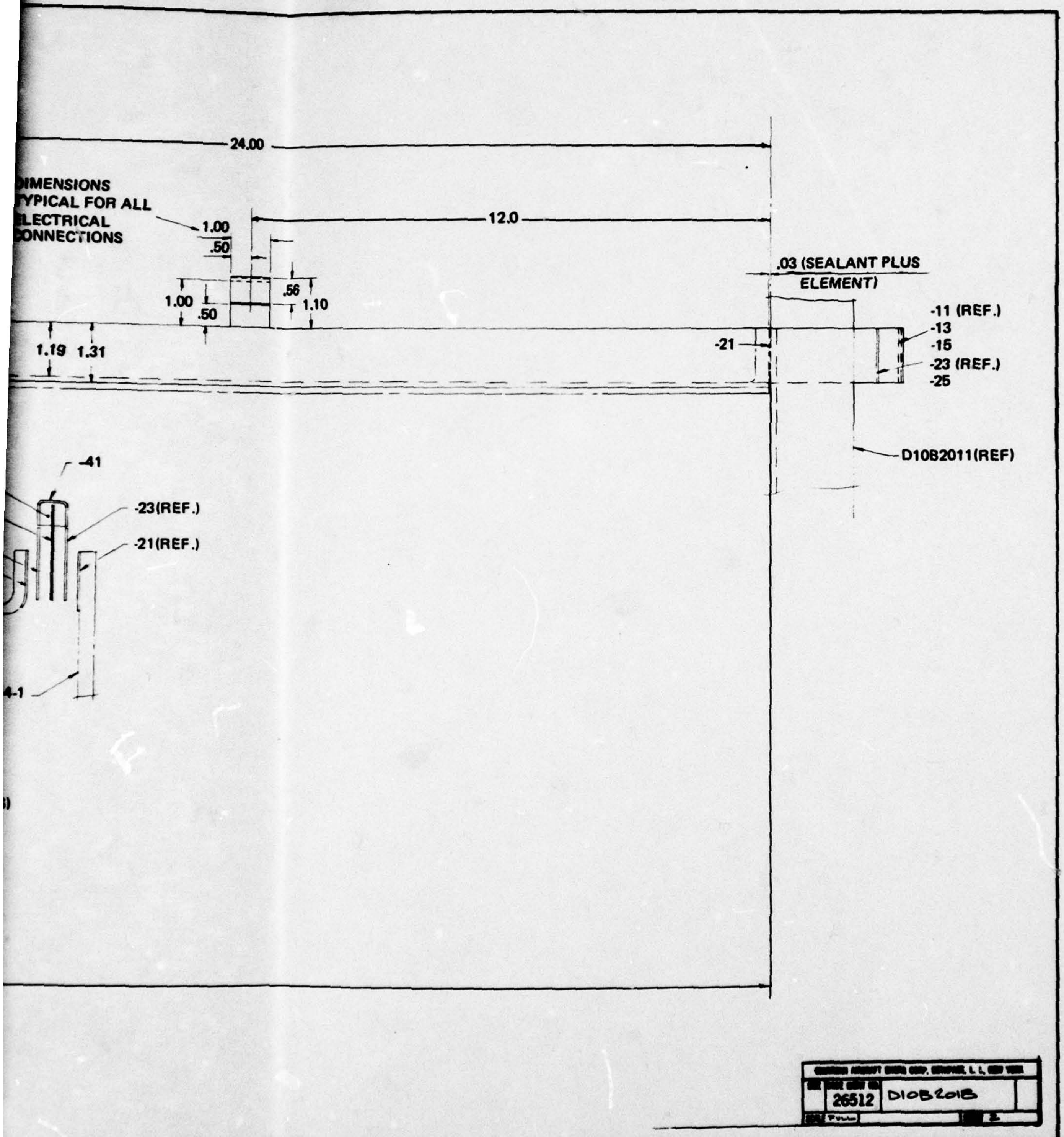


Fig. 55 Thermoplastic Sealing Assy CTSA Box (Sheet 2 of 2)



D10B2009(REF.)
-29
-27 TO BUTT ON HORIZONTAL & BOX
-25
-11
-23
-21
SECTION A-A
(TYPICAL AT FOUR CORNERS)
TOP OF BOX
-21, -23
-25, -27
-23, -25
-21, -27
-11
C
-11(REF)(TYP)
-23, -25
(TYP.) (REF.)
EDGE OF BOX
1.19
1.31
24.00
DIMENSIONS TYPICAL FOR ALL ELECTRICAL CONNECTIONS
1.00
.50
.56
1.10
A
B
ALANT
S ELEMENT)
-45
-41
-23(REF.)
-11(REF.)
-21(REF.)
-25(REF.)
-27(REF.)
D10B2009-1 (REF.)
D10B2014-1
(REF)
D10B2010-1 (REF.)
SECTION C-C
(TYPICAL AT FOUR PLACES)
-33(REF.)
D10B2014-1
(REF.)
-11
-21
PLACES)
-23
45
-25
-31(REF.)
-27 TO BUTT ON VERTICAL ℄ BOX.
-15
-39
-47
(REF.)
-31 (REF.)
-29(REF.)
-31
(REF.)
.032 RADIUS ON CORNERS OF D10B2009 AND D10B2011 UNDER SEALANT.
HORIZONTAL
℄ BOX
-29 (REF.)
D10B2011(REF.)
D10B2009(REF.)
SECTION B-B
(TYPICAL FOUR CORNERS)
BOTTOM OF BOX
VIEW LOOKING DOWN
36.06

2


24.00
DIMENSIONS
TYPICAL FOR ALL
ELECTRICAL
CONNECTIONS
1.00
.50
12.0
.56
1.00
.50
1.10
.03 (SEALANT PLUS
ELEMENT)
-11 (REF.)
-13
-15
-23 (REF.)
-25
-21
1.19
1.31
D10B2011(REF)
-41
-23(REF.)
-21(REF.)
4-1
26512
D10B2018

3

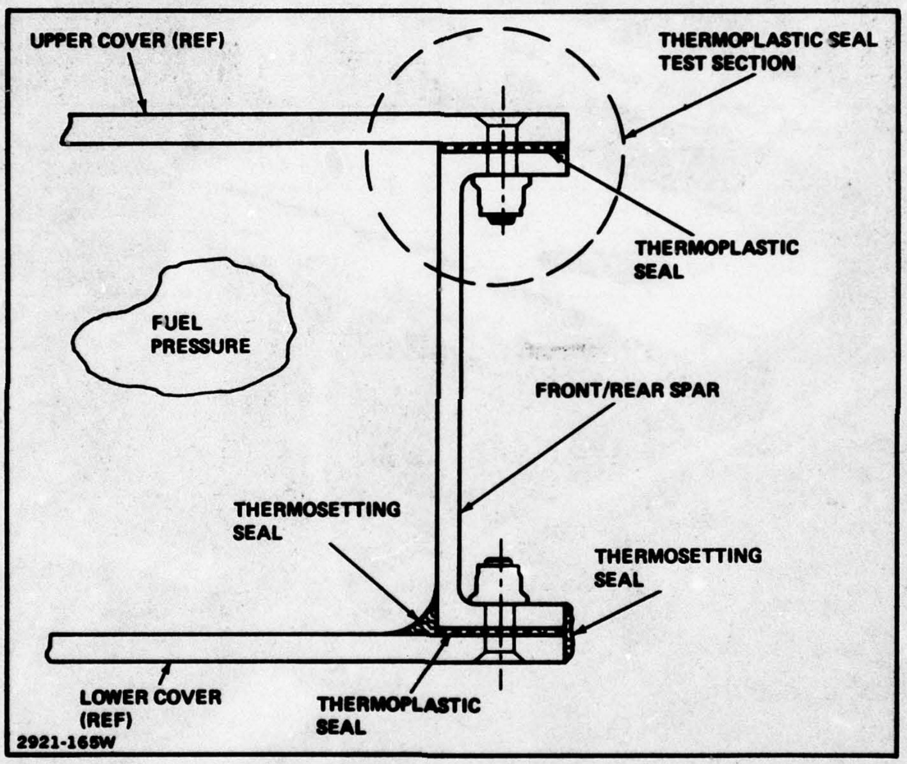


Fig. 56 Typical Cross Section of the Thermoplastic Seal Test Section

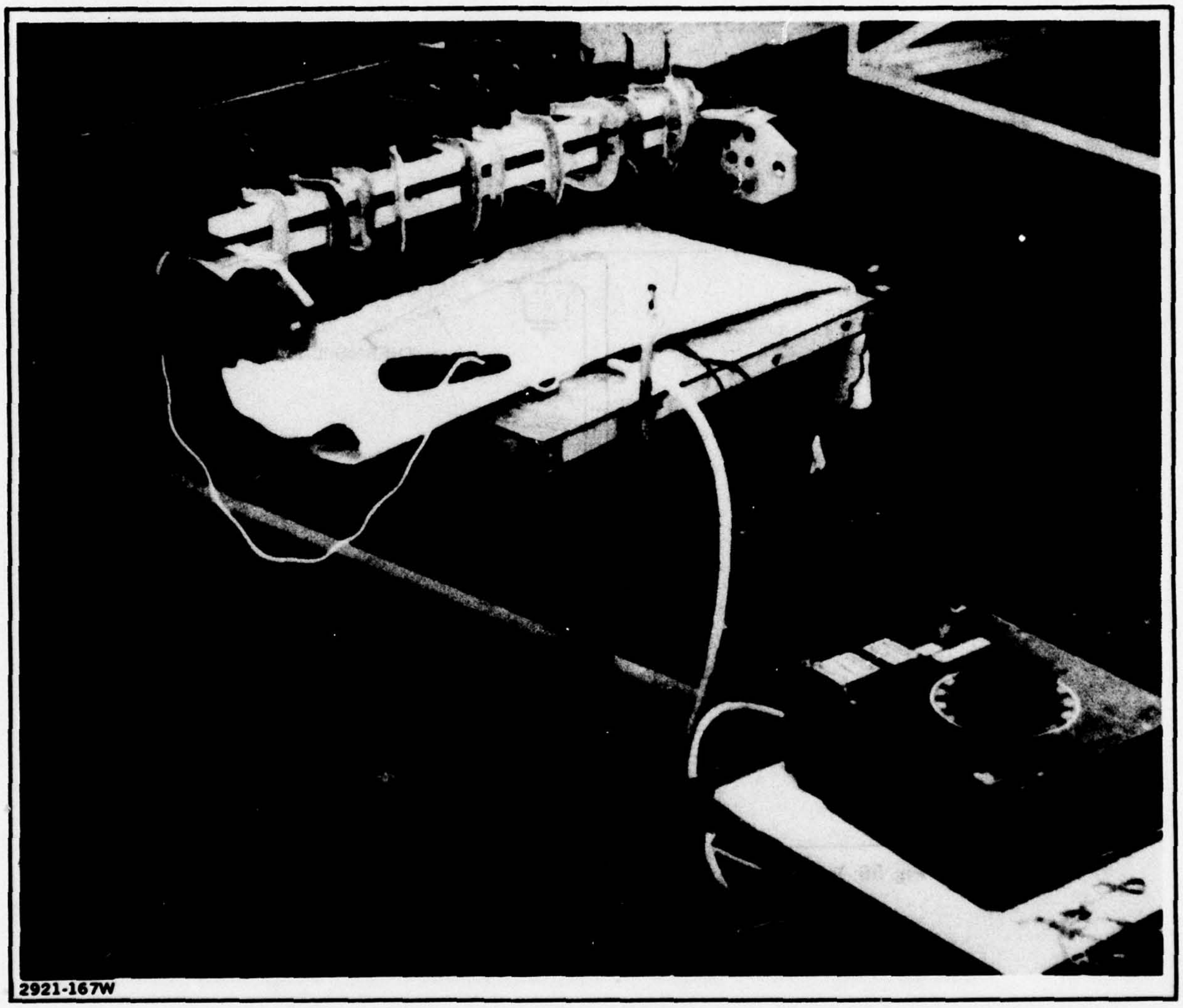


Fig. 57 Resistance Bonding of Thermoplastic Adhesive

(intersection of upper cover, front/rear spars and loading rib). This is only 2% of the total bond length (200 in.). Repeated tries to melt the unsealed area using the resistance heating method failed. This was due to the complexity of corner detail (i.e., steel rib - graphite/epoxy cover). It was decided to install the periphery fasteners and insert the test box assembly in the oven at 400° F for 15 minutes. This procedure was successful in sealing the four unsealed corners. Figure 58 graphically depicts the sealing sequence.

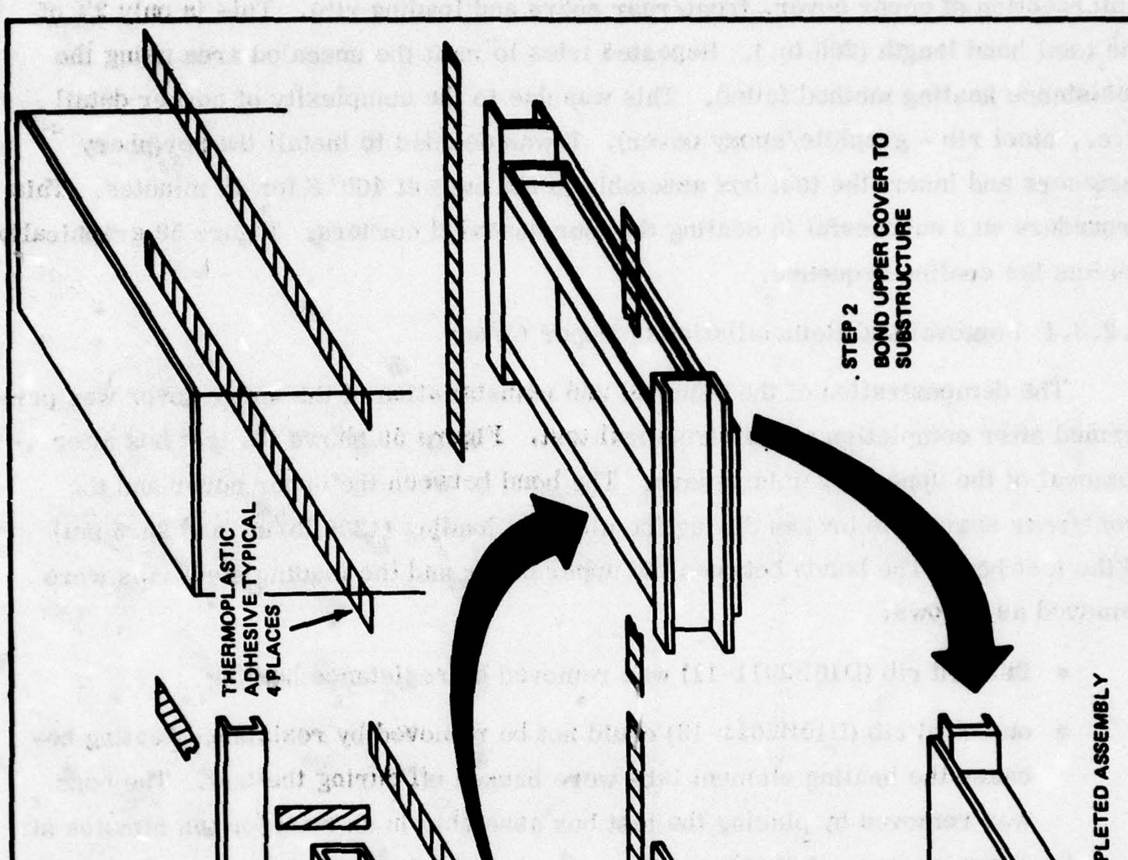
4.2.3.1 Removal and Reinstallation of Upper Cover

The demonstration of the removal and reinstallation of the upper cover was performed after completion of the structural test. Figure 59 shows the test box after removal of the upper cover fasteners. The bond between the upper cover and the front/rear spars was broken during the ultimate loading (1200 lb/in. and 95.5 psi) of the test box. The bonds between the upper cover and the loading steel ribs were removed as follows:

- inboard rib (D10B2011-11) was removed by resistance heating
- outboard rib (D10B2011-13) could not be removed by resistance heating because the heating element tabs were broken off during the test. The bond was removed by placing the test box assembly in an oven for ten minutes at a temperature of 300° F.

Figure 60 shows the upper cover and substructure after removal of thermoplastic bond.

The upper cover and substructure were cleaned in a bath of Oakite before the rebonding operation. New graphite thermoplastic heating elements were made. Using the new heating elements, an attempt was made to bond the upper cover to the substructure. This was only partially successful because only the corners were bonded. The thermoplastic adhesive was melted only in the vicinity of the tabs where the temperature was in excess of 380° F. At a distance of eighteen inches from the tab, the temperature was only 180° F. Efforts to increase the 180° F temperature by increasing the amperage failed. The rises in temperature vs. current (amps) experienced are given in Table 13. These results show that the design of the graphite heating element tabs (Fig. 61) needs more development in order to solve the local overheating problem.



2921-128W

Fig. 58 Thermoplastic Sealing Sequence

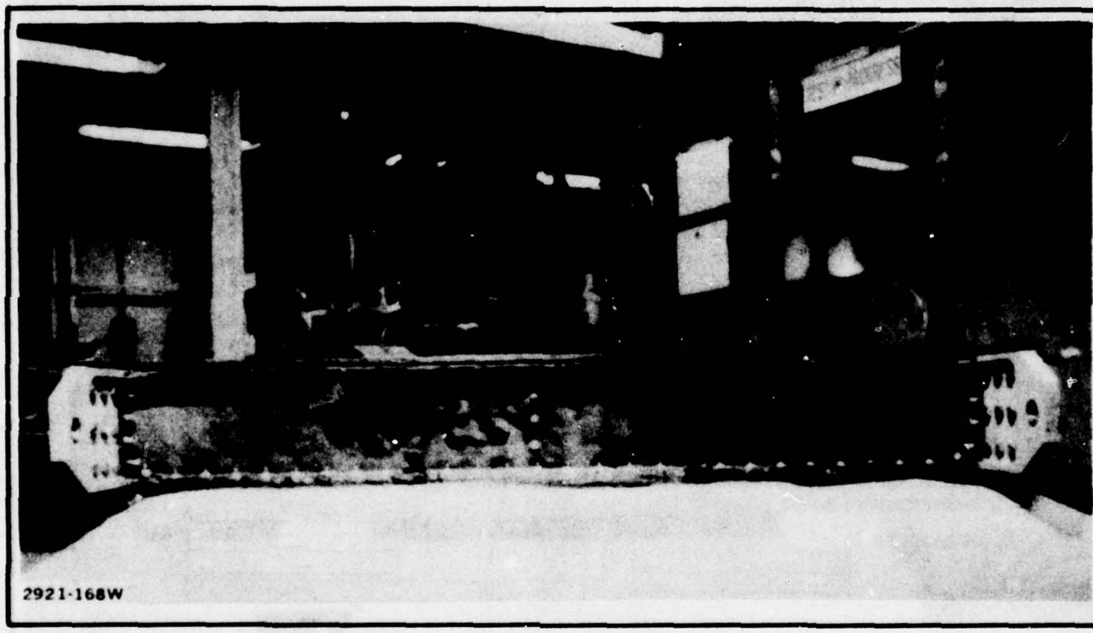
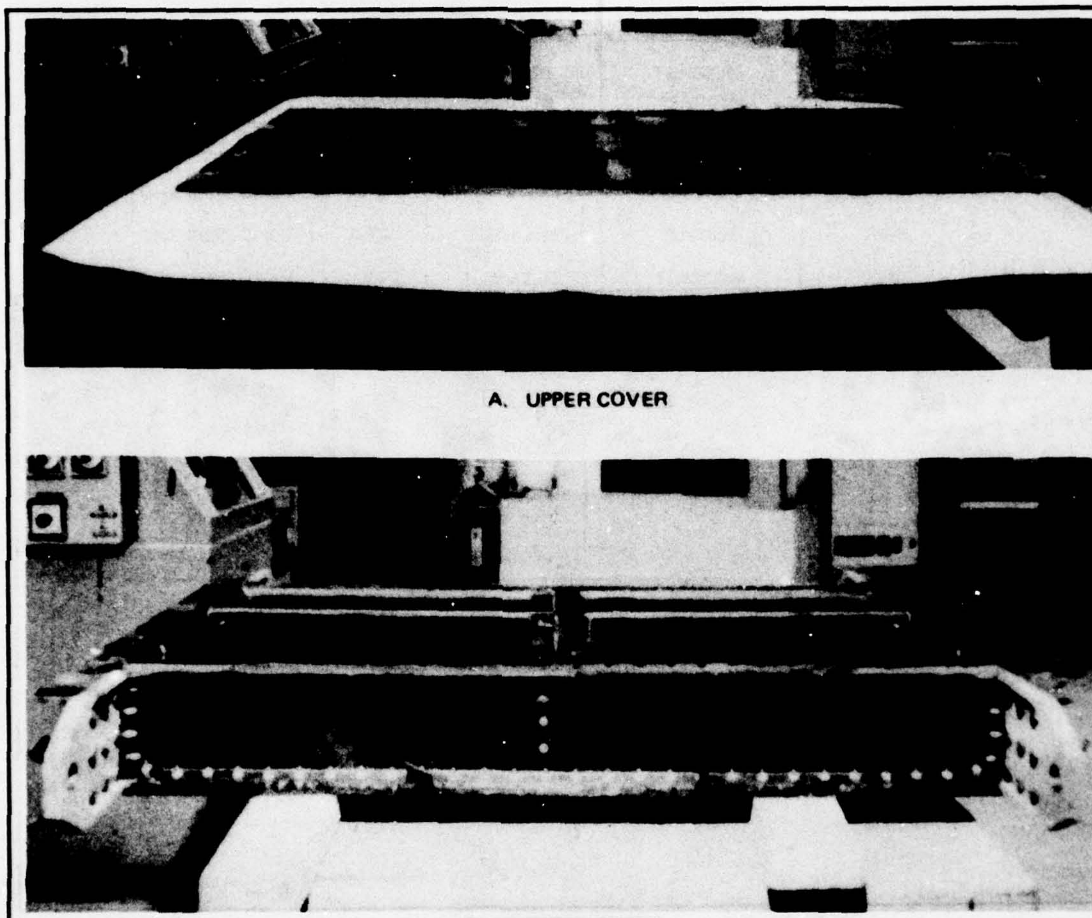


Fig. 59 Test Box After Removal of Upper Cover Fasteners



A. UPPER COVER

B. SUBSTRUCTURE

2921-169W

Fig. 60 Test Box Showing Upper Cover & Substructure After Removal of Thermoplastic Bond

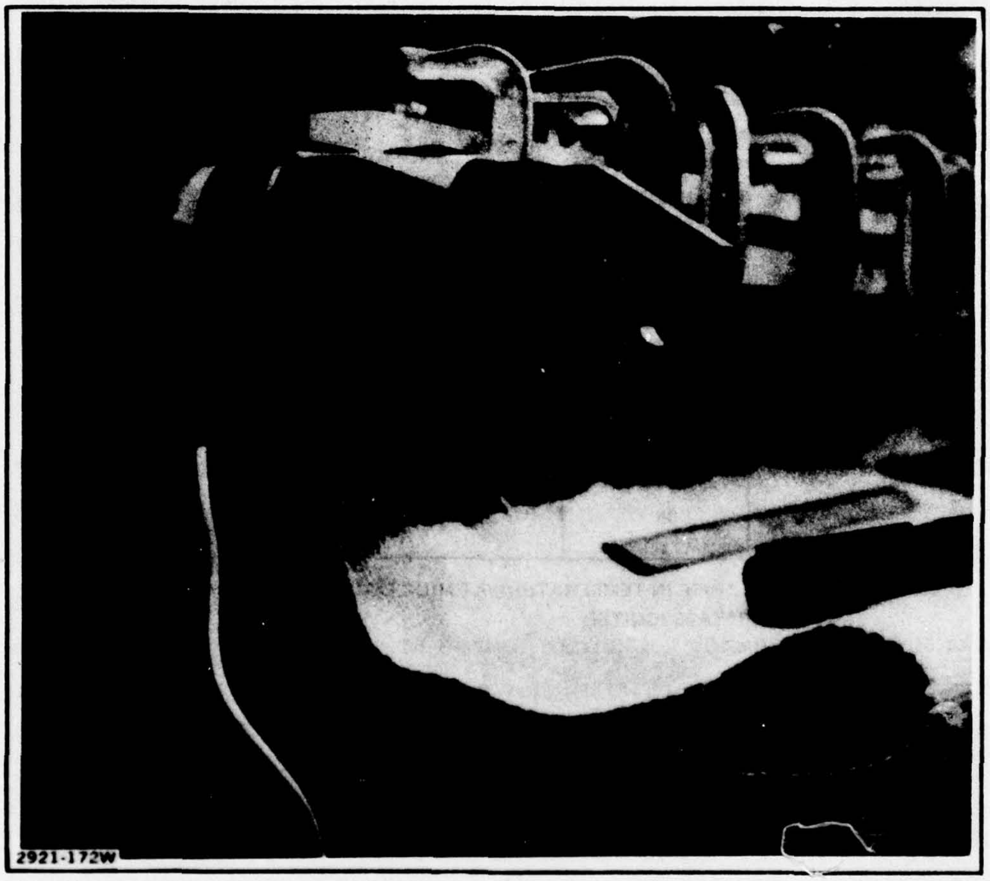


Fig. 61 Graphite Heating Element Tab

The completion of the bonding of the upper cover to the substructure was achieved by placing the test box assembly in an oven until the faying surface temperature of 380° F was obtained. The test box was then partially filled with water and a leak check performed. No leaks were detected in the thermoplastic joint.

TABLE 13
THERMOPLASTIC ADHESIVE TEMPERATURE

CUMULATIVE TIME (min)	CURRENT (amps)	TEMP° F*
0	0	72
4	2	83
9	3	104
16	4	107
23	5	126
35	7	180**
2921-171		

*RISE IN TEMPERATURE AT MID-LENGTH OF FRONT/REAR SPAR
**TABS IGNITED

SECTION V

SUBCOMPONENT FABRICATION

5.1 TEST BOX FABRICATION

The test box was fabricated during Phase II of the program. It consisted of the following detail parts:

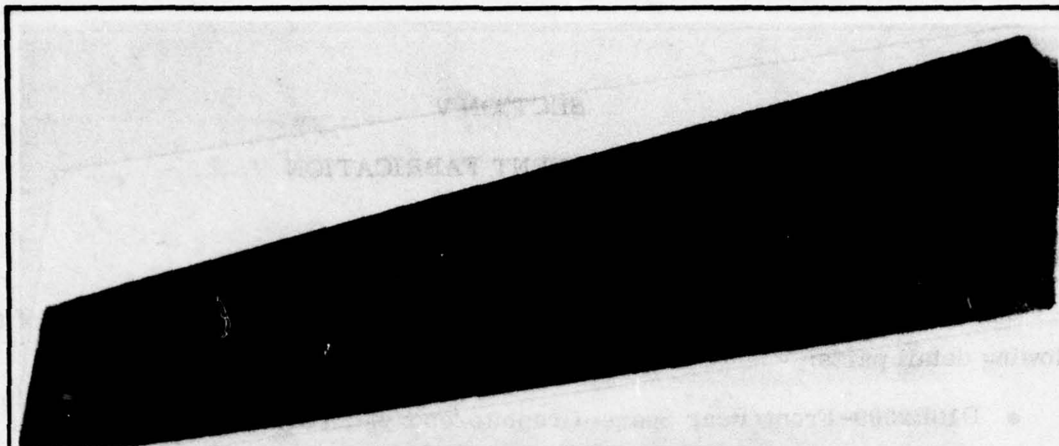
- D10B2009-Front/Rear Spars (Graphite/epoxy)-2 required
- D10B2010-Upper Cover (Graphite/epoxy)-1 required
- D10B2011-Loading Ribs (Structural steel)-2 required
- D10B2012-Intermediate Spars (Graphite/epoxy)-4 required
- D10B2013-Central Rib (Graphite/epoxy)-1 required
- D10B2014-Stitched Lower Cover Assembly (Graphite/epoxy)-1 required
- D10B2015-Test Box Assembly-1 required.

5.1.1 Front and Rear Spar (D10B2009) Fabrication

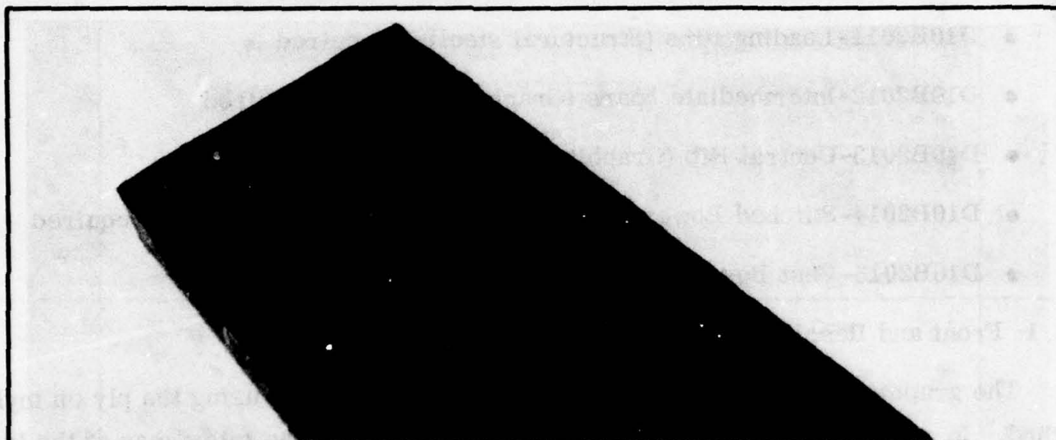
The graphite/epoxy front and rear spars were fabricated using the ply on mylar method. In order to satisfy the fuel sealing requirement at the interfaces of the loading ribs and upper and lower covers, they were manufactured with integral bathtub type ends (Fig. 62) thus eliminating the need for a mechanically attached and sealed machined fitting. The close tolerance (±0.005 inch) needed for fuel tight joints was obtained by secondarilly bonding sacrificial layers of glass/epoxy that then were machined to meet the required tolerance (Fig. 63).

5.1.2 Upper Cover (D10B2010) Intermediate Spars (D10B2012) Single Cure Process

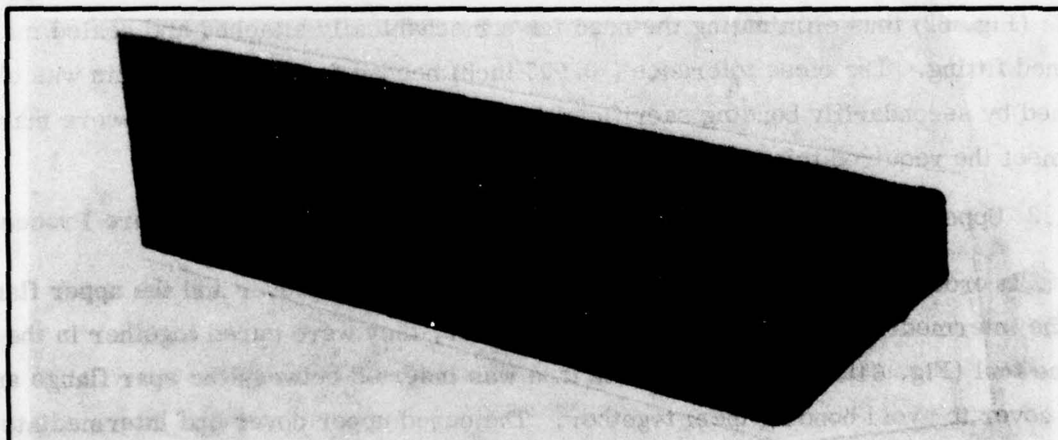
In order to assure that the inner surface of the upper cover and the upper flange of the intermediate spars match the same contour, they were cured together in the same tool (Fig. 64). A layer of mylar tape was inserted between the spar flange and the cover to avoid bonding them together. The cured upper cover and intermediate



A. OVERALL VIEW OF TOOL SURFACE



B. CLOSE-UP OF TOOL SURFACE



2921-173W C. CLOSE-UP OF BAG SURFACE

Fig. 62 Front/Rear Spar

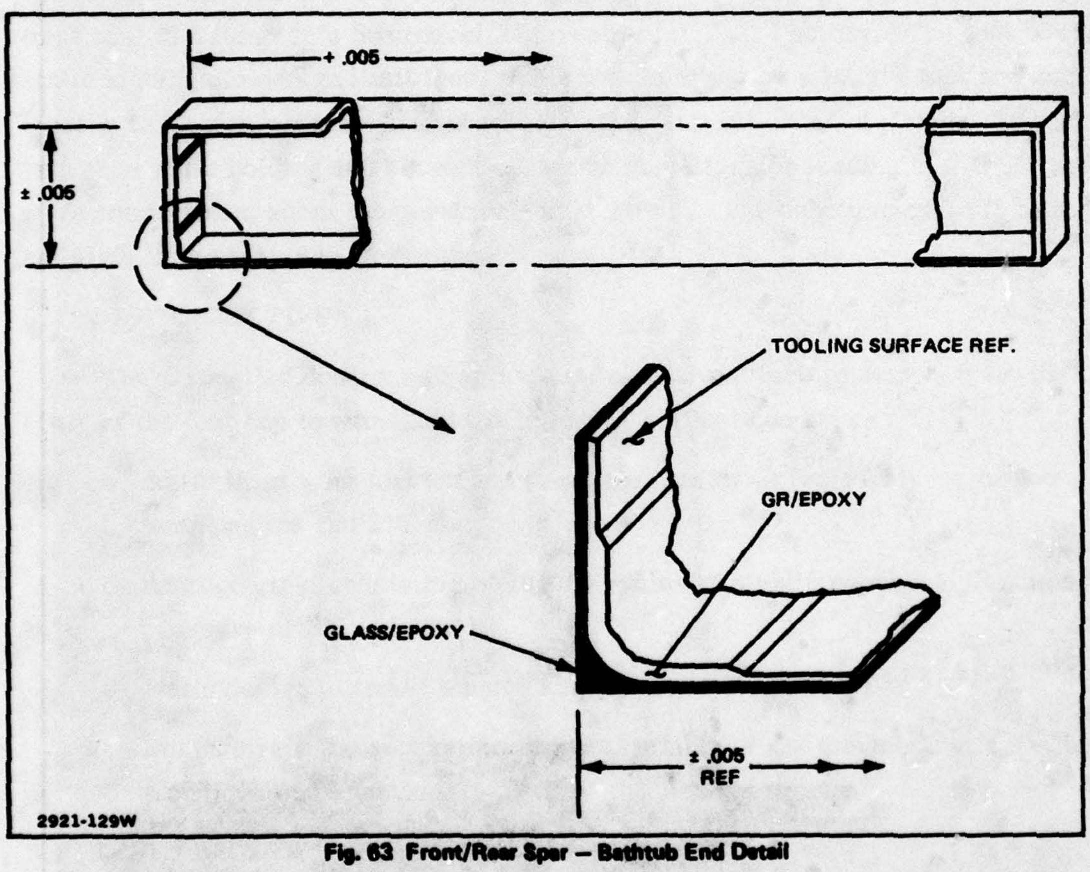


Fig. 63 Front/Rear Spar – Bathtub End Detail

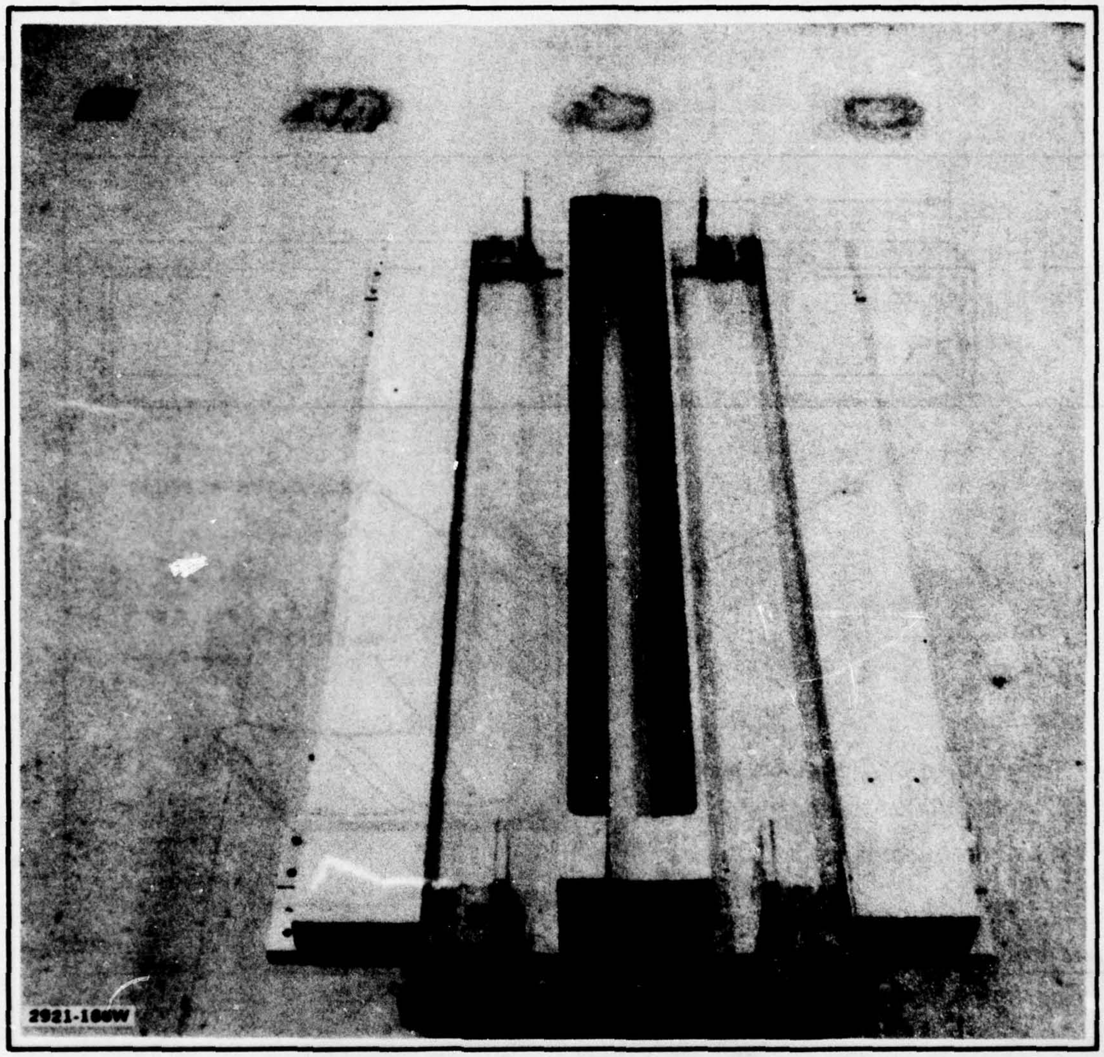


Fig. 64 Tool for Upper Cover & Intermediate Spars

spars are shown in Figure 65. The intermediate spars were then cut in two, to make the required four. This process eliminated the need for liquid shimming between the upper cover and the spars.

5.1.3 Stitched Lower Cover Assembly (D10B2014)

The lower cover and the lower angle spar cap were stitched and cured together in the same tool. The Central Rib lower angle cap was also cured in the same cure cycle. The Central Rib lower angle cap was not sewn because of the width limitation in the throat of the present sewing machine. The configuration of the lower cover-spar joint is that of Concept I ("TEE" CAP SEWN TO COVER). This configuration was selected because its geometry was compatible with present stitching capabilities. In addition, the assembly procedure for eliminating liquid shimming at the upper cover/intermediate spar interface can be best demonstrated with Concept I. This is due to the fact that Concept I has the ability to adjust in the height as shown in Fig. 66. The thread used for stitching the lower cap angles was NYMO KEVLAR (K350) which has a breaking strength of 120 lbs. The thread was coated with EPON 828 resin prior to stitching. This was done in an attempt to improve the sealing capability of the thread by reducing the wicking effect produced by dry fibers. Figure 67 shows the cured stitched lower cover assembly.

5.1.4 Test Box Assembly (D10B2015)

The test box assembly sequence was as follows:

1. The steel ribs (D10B2011) were loaded in the assembly fixture (Fig. 68A)

2. The stitched lower cover assembly (D10B2014) and the front/rear spars were loaded in the assembly fixture. Pilot hole drilling of mating surfaces was performed (Fig. 68B)

3. The intermediate spars (D10B2012) and the upper cover (D10B2010) were loaded in the assembly fixture and pilot holes drilled. Figures 67C and 67D show the parts after the drilling operation

4. The steel ribs, front and rear spars, and stitched lower cover assembly were thermoplastically bonded (see Section 4.2.3). The intermediate spars were installed using titanium Hi-Loks. The lower periphery fasteners were GB10F4 titanium bolts. The assembly prior to the upper cover installation is shown in Fig. 69.

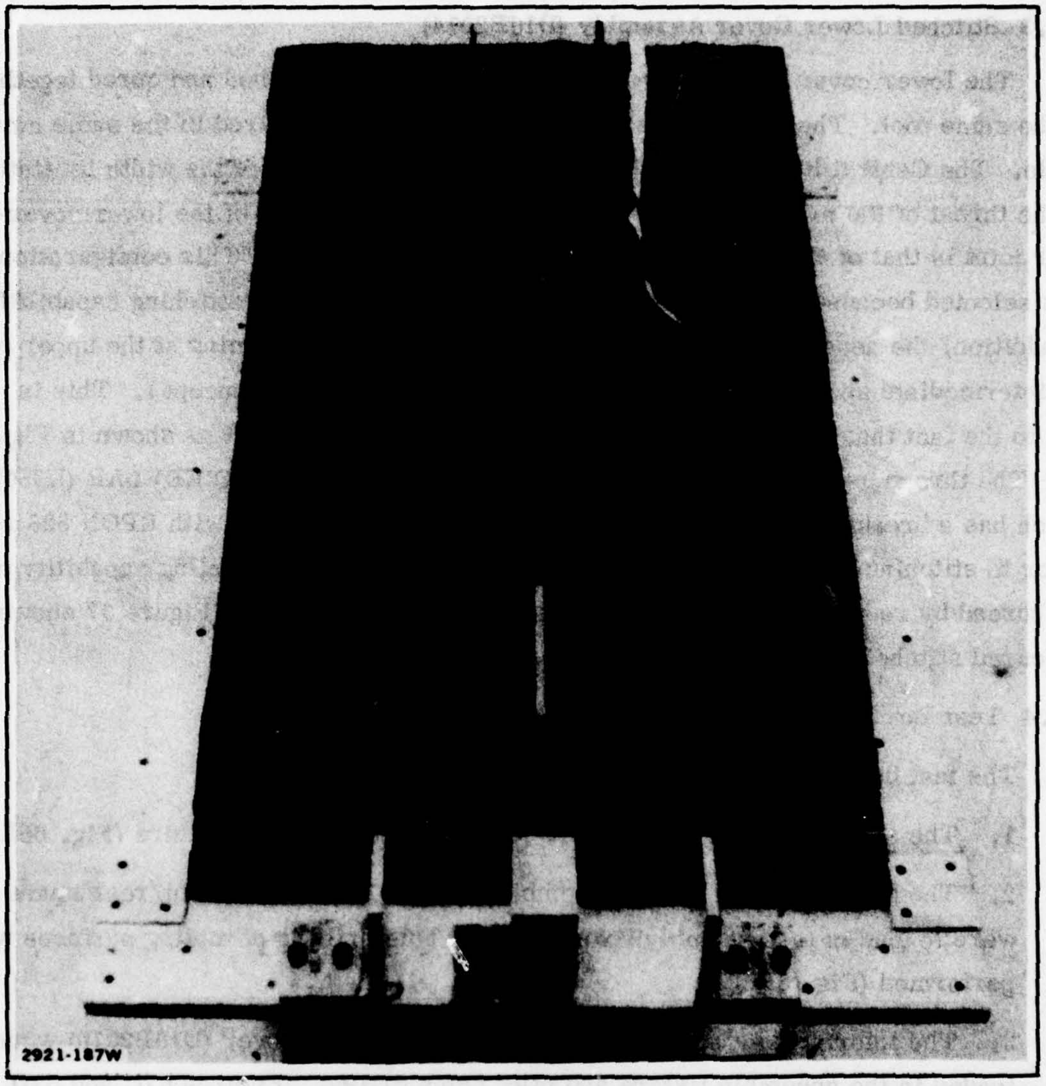


Fig. 65 Cured Upper Cover & Intermediate Spars

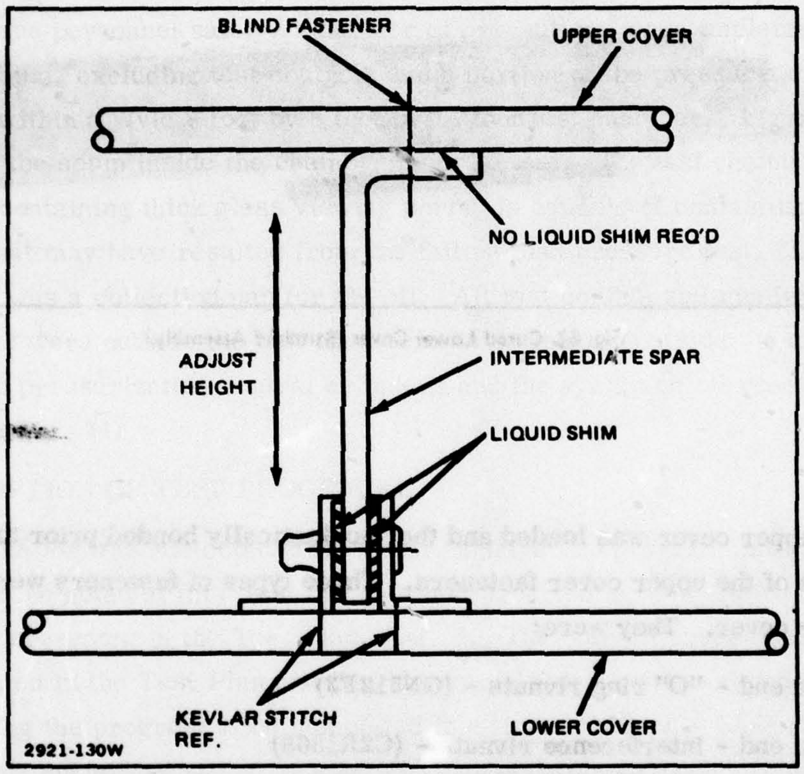


Fig. 66 Concept I – Ability to Adjust in the Height Direction

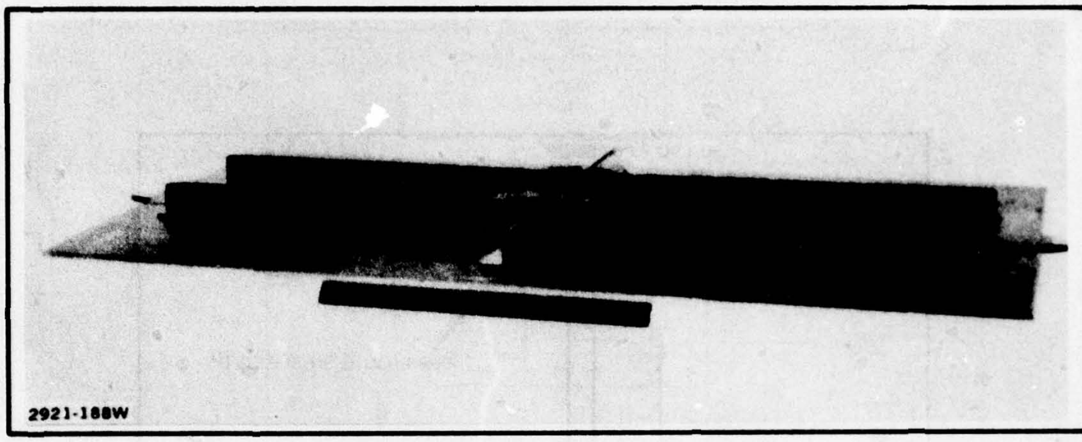


Fig. 67 Cured Lower Cover (Stitched Assembly)

5. The upper cover was loaded and thermoplastically bonded prior to the installation of the upper cover fasteners. Three types of fasteners were used in the upper cover. They were:

- Closed end - "O" ring rivnuts - (GN512F3)
- Closed end - interference rivnuts - (C2R1868)
- Titanium Bolts with "O" ring (GB510F4)

The completed assembly is shown in Figure 70.

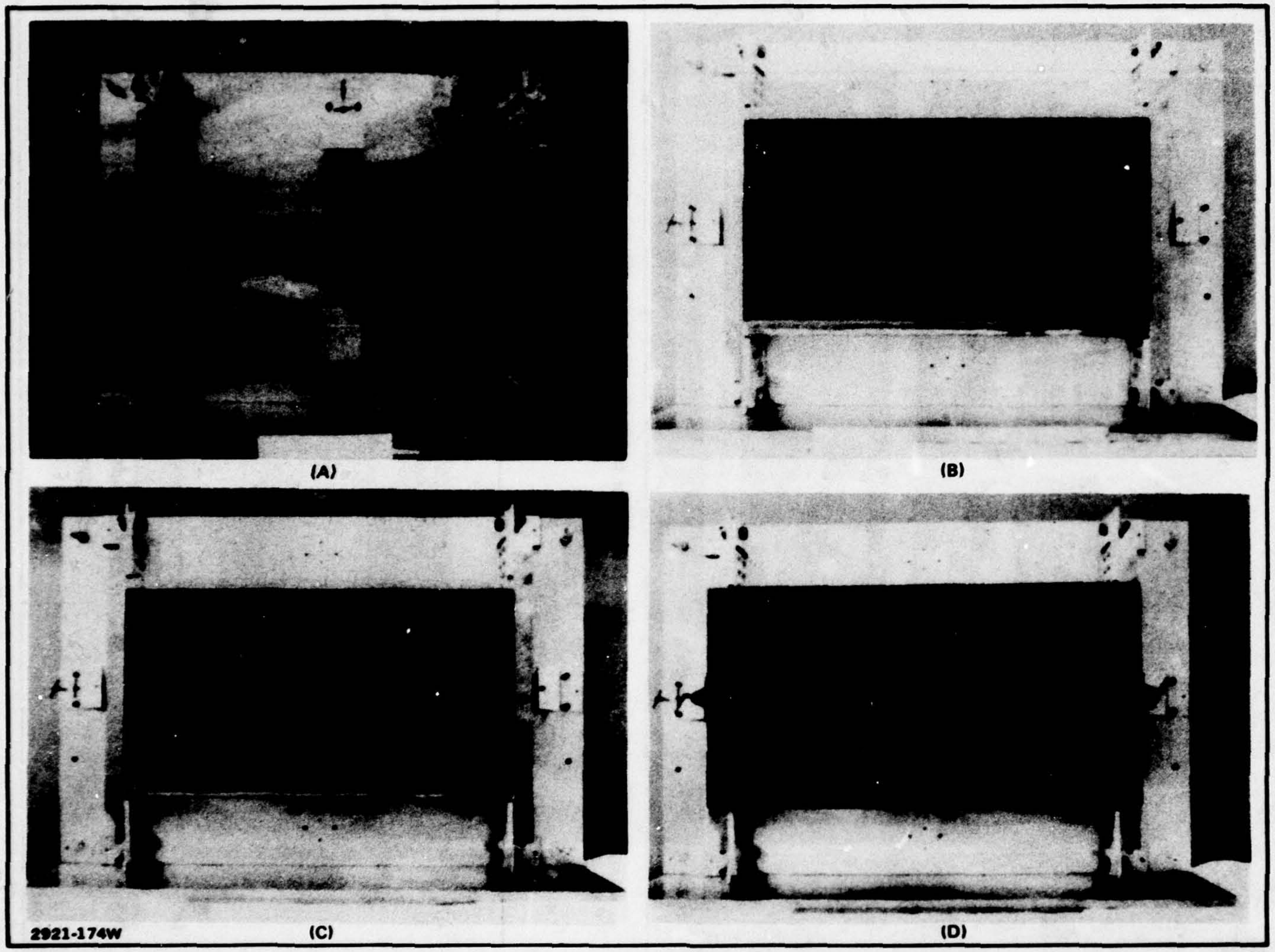


Fig. 68 Test Box Assembly Sequence

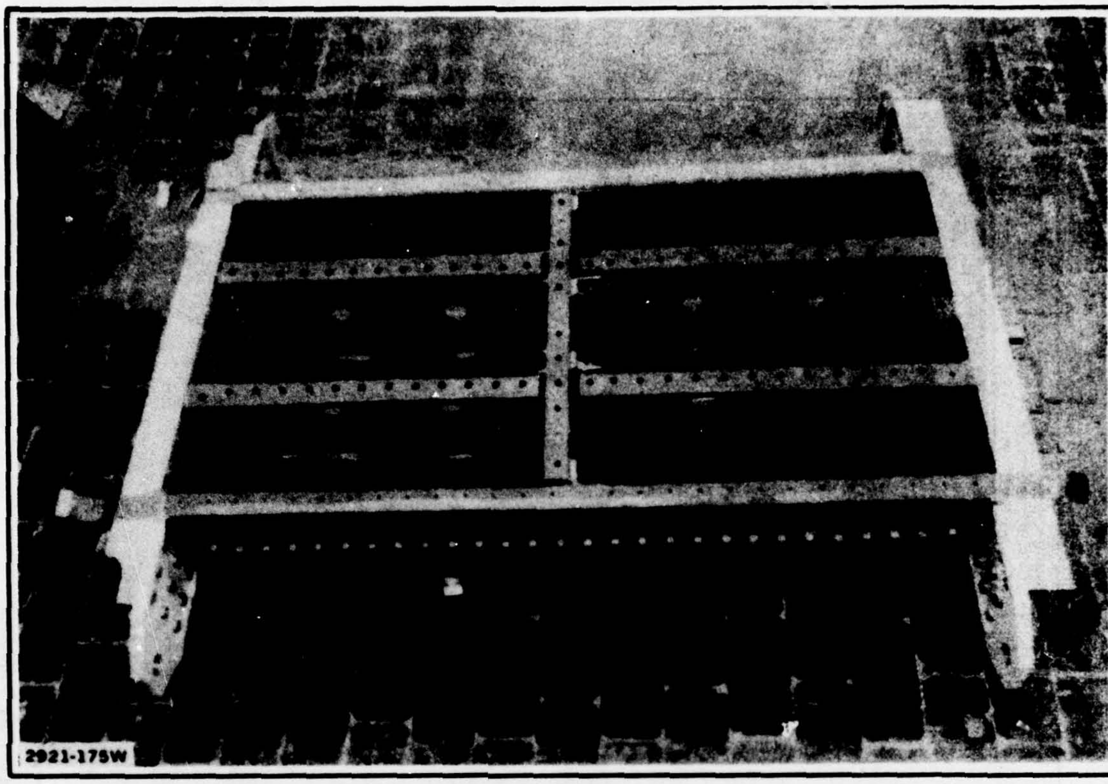


Fig. 69 Test Box Assembly – Prior to Installation of the Upper Cover

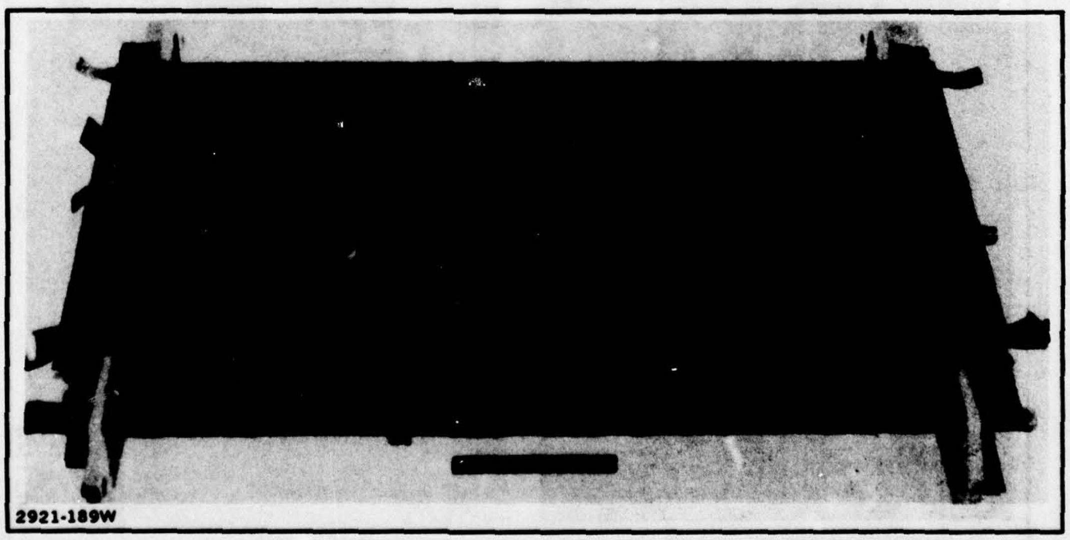


Fig. 70 Completed Test Box Assembly

SECTION VI

SUBCOMPONENT TEST AND FAILURE ANALYSIS

The Advanced Composite Wing Cover-To-Substructure Attachment (CTSA) Development Program was successfully completed with the test of the subcomponent (test box) in Grumman's Structural/Environmental Test Facility. The test box withstood static loadings to design limit load. This was followed by a fatigue test and subsequent loading to design ultimate and eventual failure at 191 percent design ultimate fuel pressure while holding 100 percent design ultimate torsion loading at 270°F. Tests were conducted at room temperature and at 270°F. The specimen met all criteria set forth in the test plan (Reference 6).

6.1 TEST OBJECTIVES

The CTSA Development Program test objectives were to demonstrate the capability of the test box to withstand the following critical conditions:

- Static limit wing torsion and pressure loading at temperatures of room temperature and 270°F
- A fatigue test consisting of 10,000 cycles of simultaneous wing torsion and pressure at RT and 270°F
- Static design ultimate torsion and pressure loads at 270°F
- Demonstrate the separation and reassembly of the thermoplastic sealing technique employed.

6.2 TEST RESULTS

The CTSA test box successfully withstood static limit loading in the most critical conditions followed by a fatigue test consisting of 10,000 cycles of zero-to-limit-to-zero loading. Following the fatigue test, the specimen sustained 100% design ultimate load in the most critical condition (combined torsion and pressure at 270°F). The test box failed at 191% design ultimate fuel pressure while holding a constant 100% design ultimate torsion load. The maximum fuel pressure attained during the failing load run

was 95.5 psi. A post-test inspection of the box revealed nine upper cover-to-intermediate-spar fasteners failed in net tension.

6.3 TEST SPECIMEN AND CONFIGURATION DATA

The Cover-To-Substructure Attachment test box, a multicelled graphite/epoxy wing section, consisted of an integral lower cover, front and rear spars, two intermediate spars, one rib and a mechanically attached upper cover. Specially designed metal end ribs were included for proper load introduction and reaction. The test box (excluding closure ribs) was 36.00 in. long, 20.50 in. wide and 5.25 in. deep. Grumman drawing D10B2016, Rev. A, dated 22 Feb. 1978 illustrates the structural arrangement of the test box. Provisions for removal of entrapped air during pressure testing were included in the form of removable fasteners in the upper cover. Pressurization was accomplished by standard bulkhead fittings located in the metal closure ribs. Figure 71 is a schematic drawing of the test box including the provisions for load and pressure application.

6.4 DESCRIPTION OF TEST SETUP

The test box was installed in a self-contained structural steel test fixture designed to apply and react the required torsion loading. Test loads (torsion) were applied by two hydraulic loading cylinders located at one of the steel closure ribs as shown in Figure 71. To preclude the introduction of any bending moment to the specimen while permitting rotation of the loaded end of the box the loaded closure rib was designed with a circular steel shaft welded to the web, equidistant between the upper and lower covers and the front and rear spars. This installation is shown in Fig. 71. Deflection data recorded throughout the test program verified that this design did in fact permit the desired rotation of the box, while at the same time eliminating any bending.

Multicircuit calibrated load cells installed inline with the hydraulic loading cylinders were continuously monitored to control and record the applied test loads.

When required, the test box was pressurized (simulated fuel pressure) with Mobil Jet oil number 2 (MIL-L-23699, flash point of 500°F) introduced through the bulkhead fittings located in the closure ribs (see Fig. 71). Entrapped air was bled from the specimen by partial removal of fasteners located in the upper cover. In addition to providing pressurization capabilities, the oil also served to heat the box

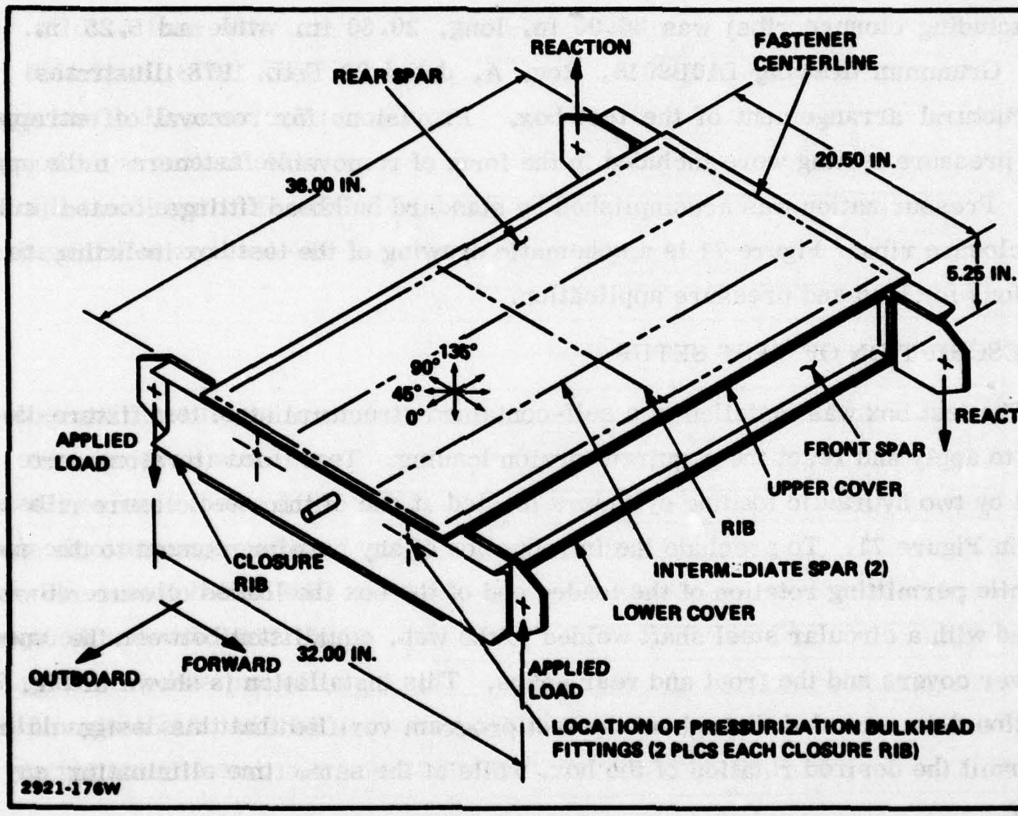


Fig. 71 Schematic Diagram of Cover-to-Substructure Attachment Test Box Including Load & Pressure Application Provisions

structure to the desired elevated temperature, when required. The oil was heated to the test temperature external of the test box by a specially designed heat exchange system and then circulated through the specimen until the specimen achieved the desired temperature. Thermocouples installed at critical locations on the test specimen, as well as within the environmental control system, were continuously monitored during test.

A schematic diagram of the load, pressure and temperature systems is presented in Fig. 72.

To insure personnel safety, a number of precautions were implemented. The entire test setup, excluding test controls and a portion of the pressurization apparatus, was located within a Wyle 8 foot by 8 foot by 16 foot test chamber. Figure 73 provides two views of the setup inside the chamber prior to test. The test chamber, fabricated of steel and containing thick glass viewing ports, is capable of containing any shrapnel and hot oil that may have resulted from the failing load pressure test. Located within the chamber was a collection pan for the oil. All test control and monitoring equipment and personnel were outside the test chamber. Also located outside the chamber were the specimen pressurization control cylinders and the specimen oil reservoir which are shown in Fig. 74.

6.5 DESCRIPTION OF TEST PROCEDURE

The test box was subjected to the comprehensive test program outlined in Table 14. It should be noted at this time that this test program agrees almost exactly with the program presented in the Test Plan, Ref. 6. The only difference between the program presented in the Test Plan and that shown in Table 14 was a reordering of the tests, enabling the program to be completed in a timely fashion. No deletions or additions were made.

For test number one, the specimen was filled with water and an attempt made to pressurize the box to 25 psig. After replacing the corner Hi-Lok collars and retightening the periphery fasteners, a second run was made, this time to 25 psig. This test resulted in a significant reduction of the leakage rate. A third and final run was made after the box was vented. Pressure was applied to 25 psig and held for 25 hours.

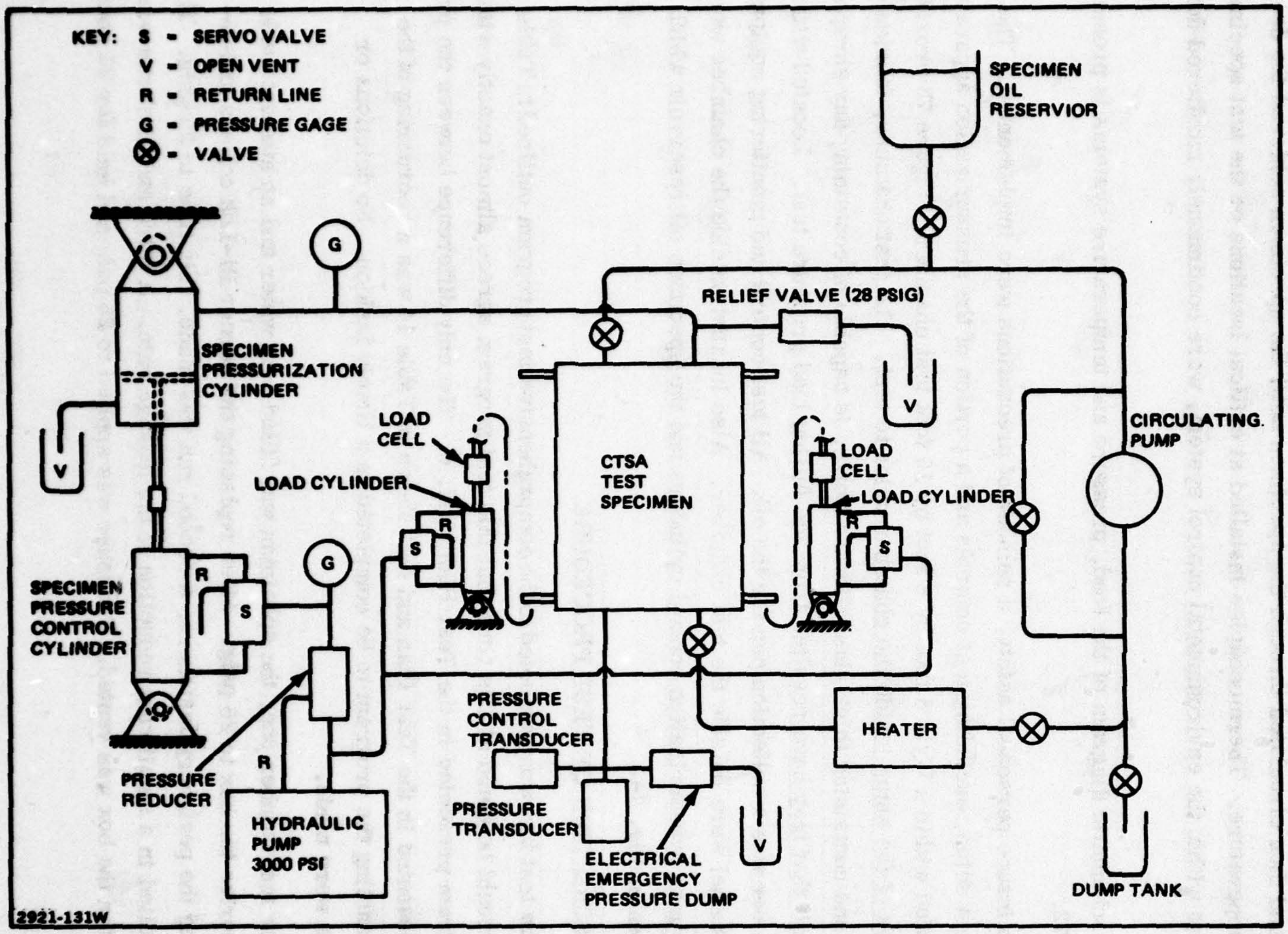


Fig. 72 Schematic Diagram of Load, Pressure & Temperature Systems

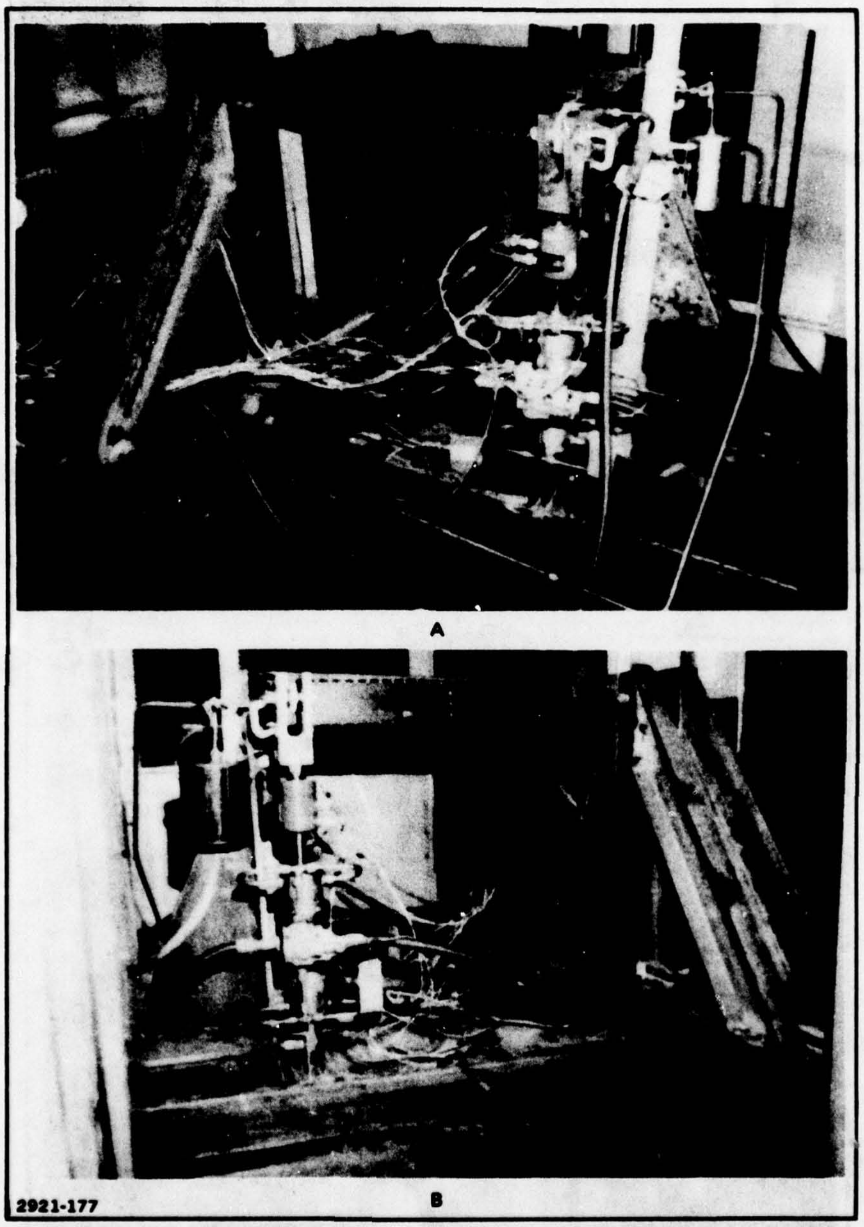
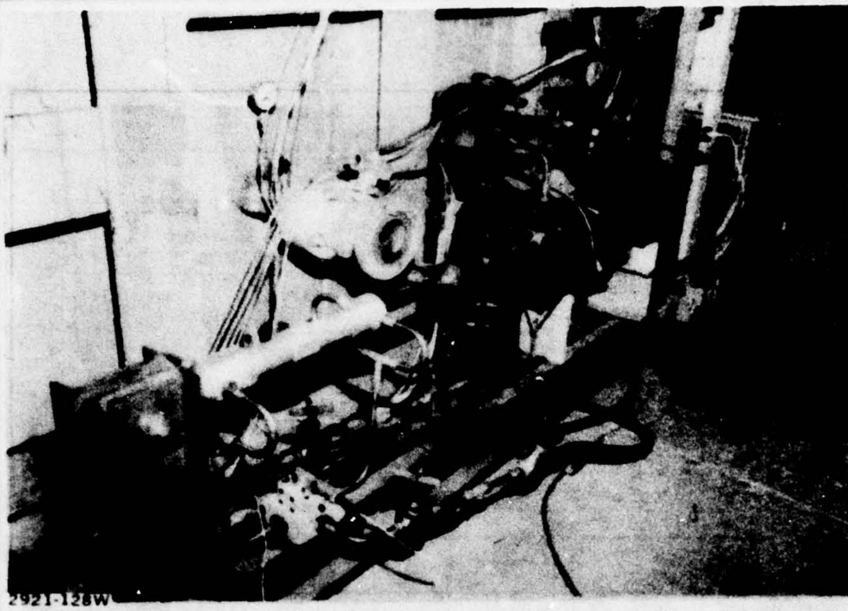
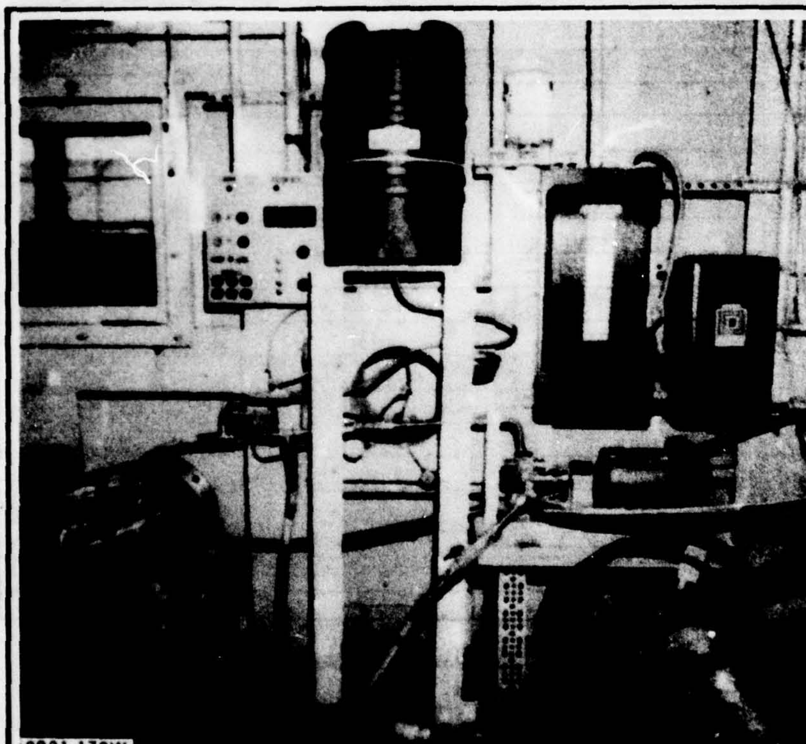


Fig. 73 View of CTSA Test Box/Fixture Assembly Installed in Wyle Chamber Prior to Test



(a) PRESSURIZATION CYCLINDERS



(b) OIL RESERVOIR

Fig. 74 – CTSA Test Box Pressurization Apparatus

TABLE 14 CTSA TEST PROGRAM

TEST NUMBER	TEST DESCRIPTION	MECHANICAL LOAD SHEAR, LB/IN. LIMIT -800	MECHANICAL LOAD SHEAR, LB/IN. ULTIMATE -1200	PRESSURE LOAD, FUEL PRESSURE, PSI LIMIT 25	PRESSURE LOAD, FUEL PRESSURE, PSI ULTIMATE 50	TEMPERATURE RT	TEMPERATURE 270°F
1	PRESSURE CHECK (1)			X		X	
2	MECHANICAL LOAD CHECK	X				X	
3	TEMPERATURE SURVEY						X
4	MECHANICAL & PRESSURE (2)	X		X		X	
5	MECHANICAL & PRESSURE & TEMPERATURE	X		X			X
6	FATIGUE (3)	X		X		X	X
7	125 PERCENT DLL	X1.25		X1.25			X
8	DESIGN ULTIMATE/ FAILURE (4)		X		X		X
9	THERMOPLASTIC SEALING DEMONSTRATION						
2921-179							

NOTES:

(1) WATER USED AS THE PRESSURIZING MEDIUM

(2) MOBIL JET OIL NUMBER 2 (MIL-L-23699) USED FOR THIS AND ALL SUBSEQUENT PRESSURIZATIONS.

(3) CYCLE FUEL PRESSURE LOAD (0 PSI TO 25 PSI TO 0 PSI) AND SHEAR LOAD (0 LB/IN. TO -800 LB/IN. TO 0 LB/IN.) SIMULTANEOUSLY TEN THOUSAND TIMES. NINETY PERCENT OF CYCLES AT ROOM TEMPERATURE, TEN PERCENT AT 250 to 270°F.

(4) INCREASE SHEAR LOAD AND PRESSURE LOAD TO ULTIMATE. HOLD SHEAR LOAD CONSTANT AND CONTINUE TO INCREASE PRESSURE LOAD TO FAILURE.

Test number two subjected the box to design limit shear load of -800 lb/in. The specimen was loaded in increments to design limit with specimen loads and deflections continuously recorded. Upon attainment of design limit the applied load was returned to zero. The Log of Test for this test is presented in Fig. 75A.

A temperature survey, test number three, was conducted to checkout the environmental test equipment and the specimen's response. Thermocouples were continuously monitored during the run from room temperature to 250-270° F, during a hold of approximately 30 minutes at temperature, and during the return to zero.

For test number four, the test box was subjected to incremental mechanical and pressure loading to design limit at room temperature. Both the shear and pressure loads were increased proportionally throughout the run from zero load to limit. A visual leak check was made at design limit. Following completion of the leak check, the loads were returned to zero. Figure 75B is a Log of Test for this condition.

Test number five repeated the loading of test number four but at a specimen surface temperature of 250 to 270° F. A leak check at design limit load was performed. Following attainment of design limit load and the acquisition of test data, the shear load and pressure were returned to zero. The Log of Test for this test is presented in Fig. 75C.

In test number six, the test box was subjected to a combined mechanical and fuel pressure fatigue test. Ten thousand cycles of zero psi - 25 psi - zero psi fuel pressure and 0 lb/in. to -800 lb/in. to 0 lb/in. shear loading were applied simultaneously. Nine thousand cycles were applied with the test box at room temperature followed by one thousand with the box at 250 to 270° F. Figure 75D is the Log of Test for this phase of the program. Periodically during the fatigue test, visual inspections of the specimen were performed to check for leaks or structural damage.

Following completion of the fatigue test, the specimen was loaded statically to failure. The specimen was first heated to a temperature of 250 to 270° F and allowed to stabilize. Next the shear load and fuel pressure loads were increased incrementally to 125 percent design limit (test seven). Upon attainment of this load level and acquisition of data, the test loads were returned to a ten percent design limit base load and preparations were made for the failing load run, test number eight. For the failing load

LOG OF TEST

TITLE: COVER-TO-SUBSTRUCTURE ATTACHMENT PROGRAM

TEST CONDITION: LIMIT SHEAR, RT   TEST DATE: 24 OCTOBER 1978

CONDUCTED BY: R. DEVOE

RUN NO.	TEST LOAD (LBS.)	% DUL	REMARKS	PHOTO NUMBER
1	0	0		
2	675	10	BASE LOAD	
3	1350	20		
4	2025	30		
5	2700	40		
6	3375	50		
7	4050	60		
8	4500 (-800 LB/IN.)	66.7	DESIGN LIMIT LOAD	
9	675	10	BASE LOAD	
10	4500 (-800 LB/IN.)	66.7	DESIGN LIMIT LOAD	
11	675	10	BASE LOAD	
12	0	0		

CONTRACT F33615-77-C-3071

2921-180

Fig. 75A. CTSA Test Box, Test Number 2, Log of Test

LOG OF TEST

TITLE: COVER-TO-SUBSTRUCTURE ATTACHMENT PROGRAM

TEST CONDITION: COMBINED LIMIT SHEAR AND PRESSURE, RT TEST DATE: 25 OCTOBER 1978

CONDUCTED BY: R. DEVOE

RUN NO.	TEST LOADS MECH., LBS	PRESSURE, PSI	% DUL	REMARKS	PHOTO NUMBER
1	0	0	0	START FUNCTIONAL TEST	
2	675	3.75	10		
3	1350	7.50	20		
4	2025	11.25	30		
5	2700	15.00	40		
6	0	0	0	COMPLETE FUNCTIONAL TEST	
7	675	3.75	10	BASE LOAD	
8	1350	7.50	20		
9	2025	11.25	30		
10	2700	15.00	40		
11	3375	18.75	50		
12	4050	22.50	60		
13	4500 (-800 lb/in)	25.00	66.7	DESIGN LIMIT LOAD	
14	675	3.75	10	BASE LOAD	
15	4500 (-800 lb/in)	25.00	66.7	DESIGN LIMIT LOAD	
16	0	0	0		

CONTRACT F33615-77-C-3071

8081-4700

Fig. 75 B. CTSA Test Box, Test Number 4, Log of Test

LOG OF TEST

TITLE: COVER-TO-SUBSTRUCTURE ATTACHMENT PROGRAM

TEST CONDITION: COMBINED LIMIT SHEAR AND PRESSURE AT 270°F

TEST DATE: 30 OCTOBER 1978

CONDUCTED BY: R. DEVOE

RUN NO.	TEST LOADS MECH., LBS.	PRESSURE, PSI	SPECIMEN TEMP.	% DUL	REMARKS	PHOTO NUMBER
1	0	0	See Note (1)	0	Start Functional Test	
2	675	3.75		10		
3	1350	7.50		20		
4	2025	11.25		30		
5	2700	15.00		40		
6	0	0		0	Complete Functional Test	
7	675	3.75		10	Base Load	
8	1350	7.50		20		
9	2025	11.25		30		
10	2700	15.00		40		
11	3375	18.75		50		
12	4050	22.50		60		
13	4500 (-800 lb/in)	25.00		66.7	Design Limit Load	
14	675	3.75		10	Base Load	
15	0	0	See Note (1)	0		

NOTES:

(1) Upper Cover Temperature 284°F.
Lower Cover Temperature Range
266°F - 241°F.

CONTRACT F33615-77-C-3071

2021-100

Fig. 75C. CTSA Test Box, Test Number 5, Log of Test

LOG OF TEST

TITLE: COVER-TO-SUBSTRUCTURE ATTACHMENT PROGRAM

TEST CONDITION: FATIGUE TEST

TEST DATE: 30 OCTOBER 1978 to 1 NOVEMBER 1978

CONDUCTED BY: R. DEVOE

RUN NO.	TEST LOADS MINIMUM MECH.	PRESS.	MAXIMUM MECH.	PRESS.	SPECIMEN TEMP.	REMARKS	PHOTO NUMBER
1	0 lbs	0 psi	4500 lbs. (LIMIT)	25 psi	RT	9,000 CYCLES OF MINIMUM - MAXIMUM - MINIMUM	
2	0 lbs	0 psi	4500 lbs. (LIMIT)	25 psi	SEE NOTE (1)	1,000 CYCLES OF MINIMUM - MAXIMUM - MINIMUM	

NOTES: (1) UPPER COVER TEMPERATURE RANGE 282°F TO 273°F. LOWER COVER TEMPERATURE RANGE 266°F TO 230°F.

CONTRACT F33615-77-C-3071

2976-100

Fig. 75D. CTSA Test Box, Test Number 6, Log of Test

run, the box was first loaded to design limit, followed by incremental loading to design ultimate. Upon attaining design ultimate, the shear load was held constant while the fuel pressure load was increased beyond ultimate at a constant rate until failure occurred. Following completion of this test, a detailed inspection of the failed specimen was performed. The Log of Test for both the 125 percent design limit load test (number seven) and the failing load test (number eight) is presented in Fig. 75E.

At the conclusion of this test, a functional check (test number nine) of the thermoplastic sealing employed between the upper cover and substructure was conducted. This functional check is discussed in detail in subsection 4.2.3.

6.6 DISCUSSION OF TEST RESULTS

The CTSA test box successfully completed all the required test conditions shown in Table 14. The following paragraphs present a brief discussion of the progress of the individual tests and the test results obtained.

During the first test, pressure check, which consisted of three separate pressurizations, a significant reduction of specimen leakage was achieved as can be seen in Fig. 76. A discussion of this test is presented in subsection 6.5.

Following completion of the pressure checks, the specimen was subjected to design limit shear at RT (test number two), a temperature survey without loads at 270°F (test number three), combined limit shear and fuel pressure tests to design limit at RT (test number four) and 270°F (test number five). All tests were completed successfully with the results being as anticipated.

For test number six, the specimen was subjected to 10,000 cycles (9000 at RT followed by 1000 at 270°F) of 0 to design limit to 0 combined fuel pressure and shear loading. The average cycling rate for the fatigue test was approximately 11 cycles per minute. Periodically during the fatigue test, the specimen was visually inspected for leaks. Figure 77 summarizes the leaks observed during these inspections; the locations of the leaks and the times at which they were first observed are indicated. A photograph of the test box after 2000 cycles of RT fatigue showing leaks around the upper cover fasteners is presented in Fig. 78A. A close-up of one such leak is shown in Fig. 78B. In addition to leakage around the fasteners in the upper cover, some fluid weeping was noted at the stitch line in the lower cover as shown in Fig. 78C.

LOG OF TEST

TITLE: COVER-TO-SUBSTRUCTURE ATTACHMENT PROGRAM

TEST CONDITION: FAILING LOAD TEST TEST DATE: 2 NOVEMBER 1978

CONDUCTED BY: R. DEVOE

NOTES:
(1) Upper cover temperature 279°F. Lower cover temperature range 219°F - 215°F

RUN NO.	TEST LOADS MECH, LBS.	PRESSURE, PSI	SPECIMEN TEMP.	% DUL	REMARKS	PHOTO NUMBER
1	0	0	See Note (1)	0		
2	675	3.75		10	BASE LOAD	
3	1350	7.50		20		
4	2025	11.25		30		
5	2700	15.00		40		
6	3375	18.75		50		
7	4050	22.50		60		
8	4500 (-800 lb/in)	25.00		66.7	DESIGN LIMIT LOAD	
9	675	3.75		10	BASE LOAD	
10	4500 (-800 lb/in)	25.00		66.7	DESIGN LIMIT LOAD	
11	4730	26.25		70		
12	5060	28.10		75		
13	5400	30.00		80		
14	5640 (-1000 lb/in)	31.30		83.4	125% DESIGN LIMIT LOAD	
15	675	3.75		10	BASE LOAD	
16	4500 (-800 lb/in)	25.00		66.7	DESIGN LIMIT LOAD	
17	5060	28.10		75		
18	5400	30.00		80		
19	5740	31.80		85		
20	6070	33.80		90		
21	6410	35.60		95		
22	6750 (-1200 lb/in)	37.50		100	DESIGN ULTIMATE LOAD	
23	HOLD LOAD CONSTANT	INCREASE PRESSURE TO FAILURE	See Note (1)	-	FAILING LOAD RUN	

CONTRACT F33615-77-C-3071

2921-180

Fig. 75E. CTSA Test Box, Test Numbers 7 and 8, Log of Test

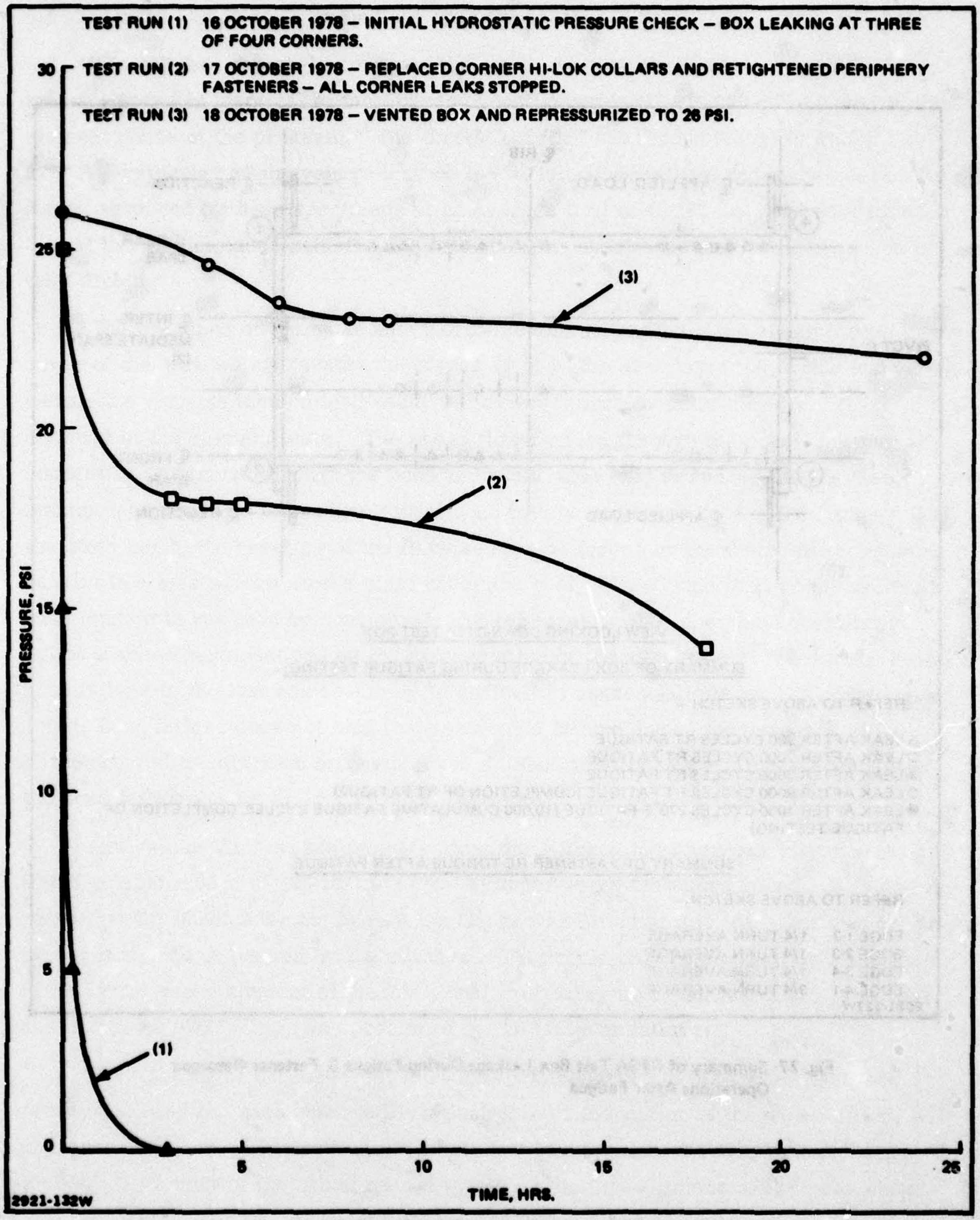
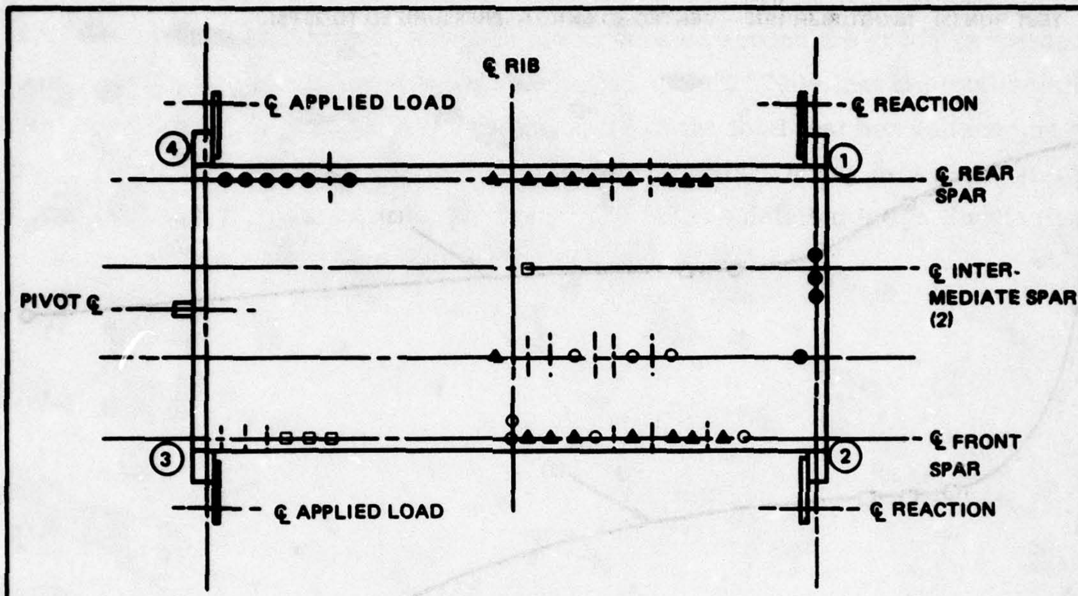


Fig. 76 Preliminary Pressure Checks of CTSA Test Box



VIEW LOOKING DOWN-CTSA TEST BOX

SUMMARY OF BOX LEAKAGE DURING FATIGUE TESTING:

REFER TO ABOVE SKETCH –

△ LEAK AFTER 900 CYCLES RT FATIGUE
□ LEAK AFTER 2000 CYCLES RT FATIGUE
▲ LEAK AFTER 3000 CYCLES RT FATIGUE
○ LEAK AFTER 9000 CYCLES RT FATIGUE (COMPLETION OF RT FATIGUE)
● LEAK AFTER 1000 CYCLES 270°F FATIGUE (10,000 CUMULATIVE FATIGUE CYCLES, COMPLETION OF FATIGUE TESTING)

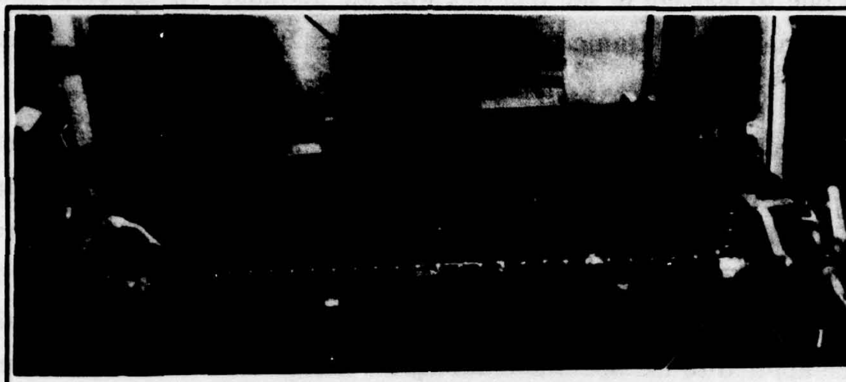
SUMMARY OF FASTENER RE-TORQUE AFTER FATIGUE

REFER TO ABOVE SKETCH –

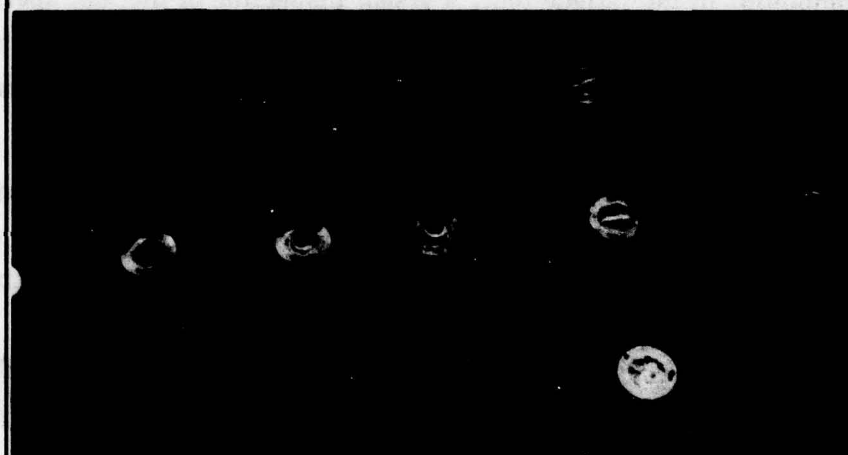
EDGE 1-2	1/4 TURN AVERAGE
EDGE 2-3	1/4 TURN AVERAGE
EDGE 3-4	1/4 TURN AVERAGE
EDGE 4-1	3/4 TURN AVERAGE

2921-127W

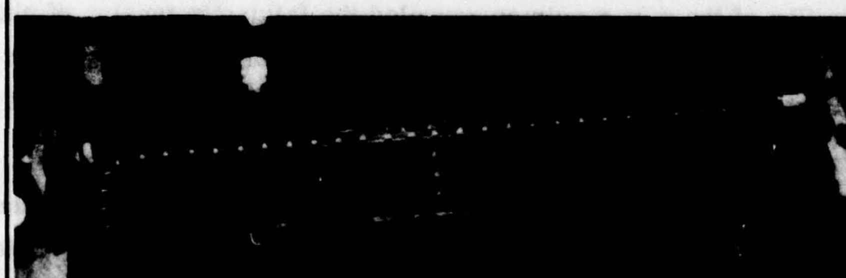
Fig. 77 Summary of CTSA Test Box Leakage During Fatigue & Fastener Retorque Operations After Fatigue



A. LEAKING AROUND UPPER COVER FASTENERS



B. CLOSE-UP OF LEAKING MS 90353-08 HUCK BOLT (REPAIR FASTENER) IN UPPER COVER



2921-181W

C. VIEW LOOKING UP AT LOWER COVER SHOWING WEEPING ALONG STITCH LINE

Fig. 78 CTSA Test Box After 2000 Cycles of RT Fatigue

Throughout the RT portion of the fatigue test, a cumulative total of pressurizing fluid lost due to leakage of the test box was maintained. At the conclusion of 9000 cycles of RT fatigue the total amount of fluid lost was 103.37 in^3. This figure is only 3.2 percent of the total test box volume of 3240 in^3.

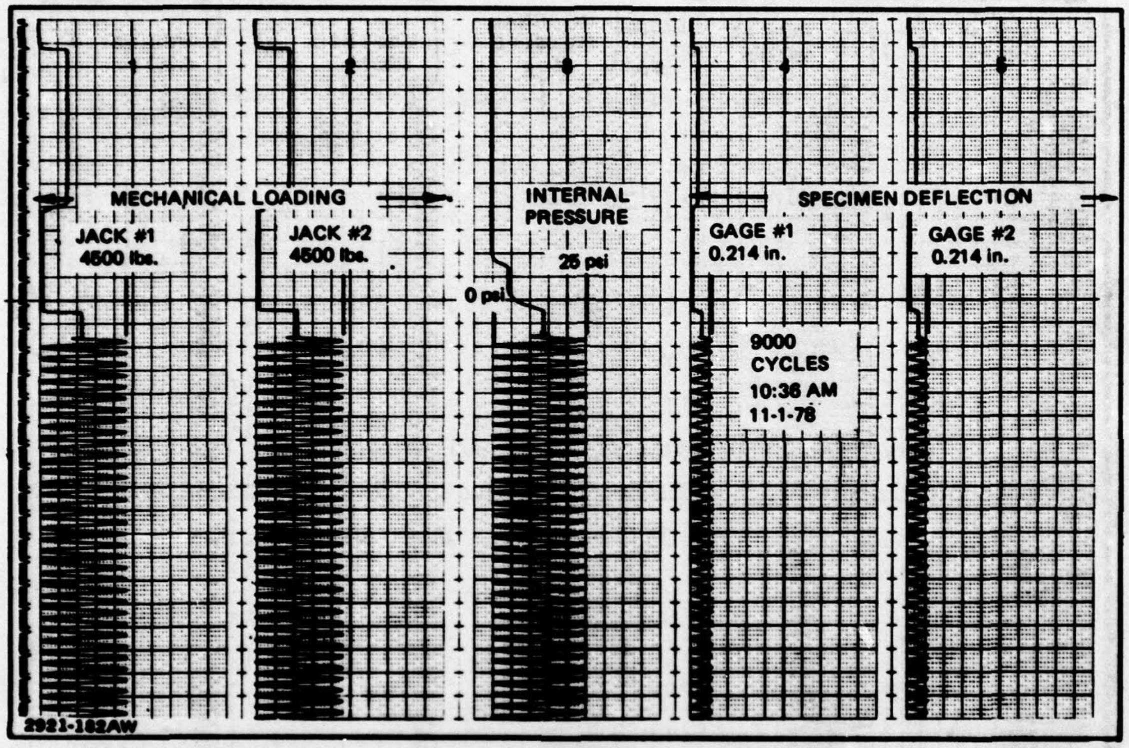
As mentioned earlier, continuous monitoring of applied shear load, internal pressure and specimen deflections was employed during the fatigue test. Figure 79 is a copy of the test records of the last few RT fatigue cycles. A similar presentation of data for the last cycles of the elevated temperature portion of the fatigue test is shown in Figure 79. Upon the completion of 10,000 cycles of fatigue, an additional 28 cycles were applied to the specimen during a demonstration for Grumman Program Management. A record of these additional cycles is also shown in Fig. 79.

Upon completion of the fatigue test, a visual inspection of the test specimen was made to check for structural damage. None was found. However, it was noticed that a number of periphery fasteners had become loose; see Fig. 77 for a summary. All fasteners were retorqued prior to continuation of testing.

Test number seven, which subjected the box to 125 percent design limit shear and pressure loading at 270°F, and test number eight, the failing load run, were performed next. The specimen successfully withstood 125 percent design limit loading followed by the successful application of 100 percent design ultimate loads. After attaining design ultimate, the shear load was held constant while the internal pressure was increased rapidly to failure. Specimen failure occurred at an internal pressure of 95.5 psig or 191 percent design ultimate load.

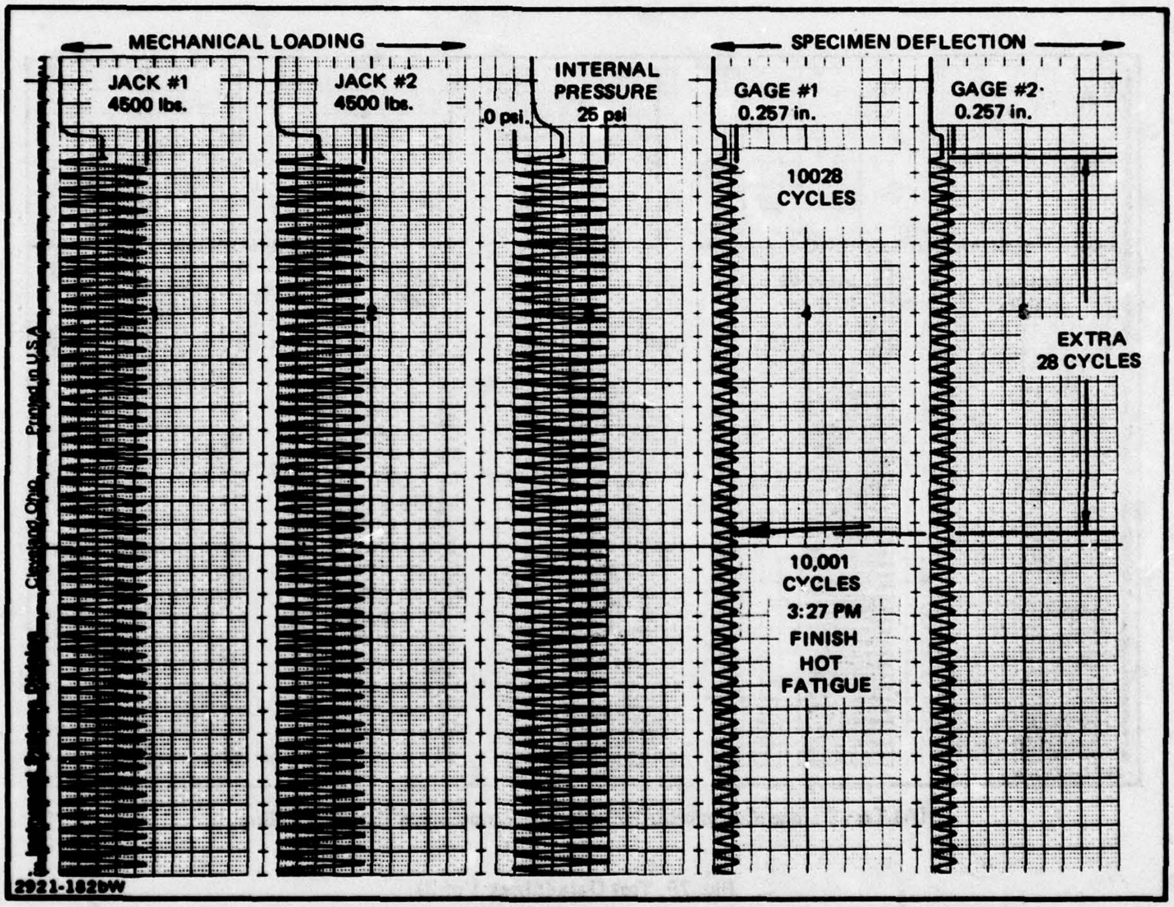
Test data recorded at the moment of failure is presented in Fig. 79C. A detailed inspection of the test specimen revealed the failure in tension of nine upper cover-to-intermediate spar fasteners and the extrusion of the thermoplastic sealing material along both the front and rear spar areas. Figure 80 is a sketch of the failure locations.

Throughout the test program, the deflection of the specimen due to shear loading was as expected. A summary of maximum specimen deflection for the various test conditions imposed is presented in Table 15.



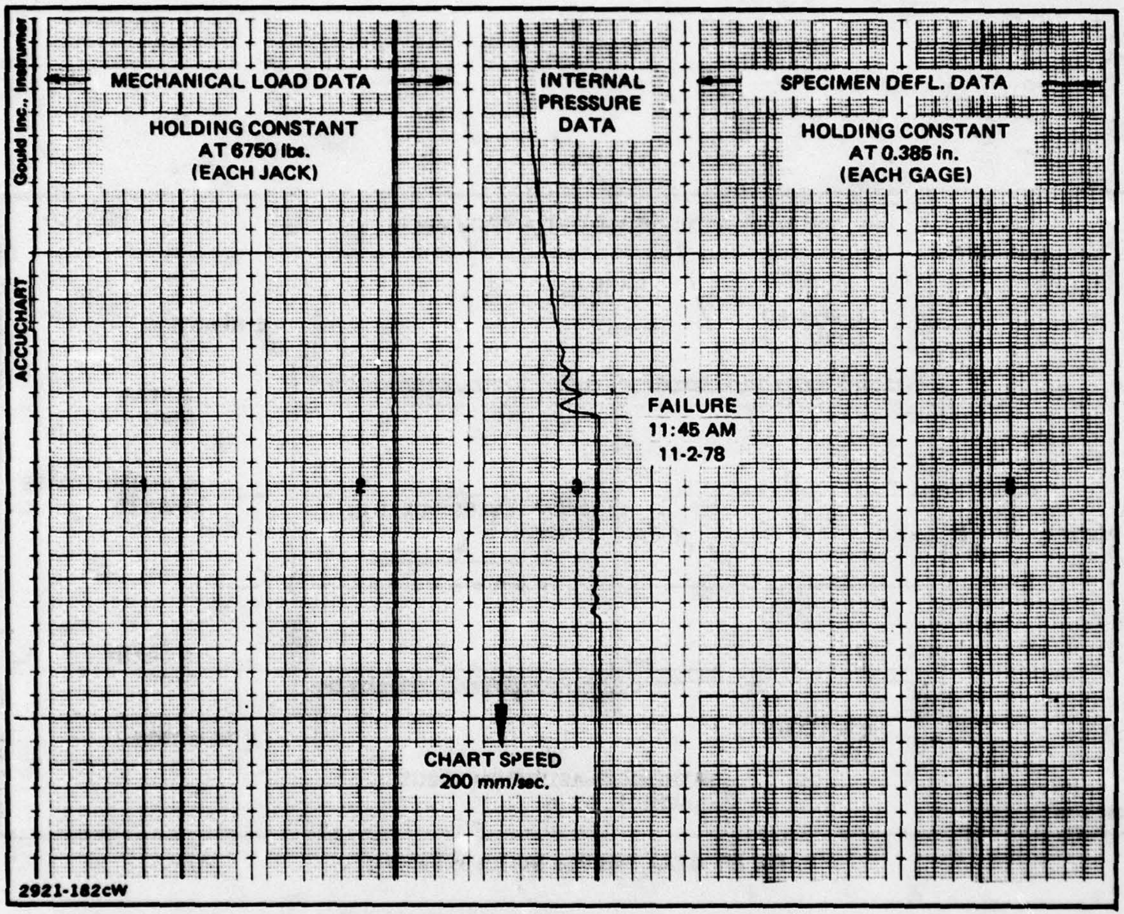
(A) Test Data at Completion of a Room Temperature Fatigue Cycling

Fig. 79 Test Data (Sheet 1 of 3)



(B) Test Data at Completion of Elevated Temperature (270^{0}F) Fatigue Cycling

Fig. 79 Test Data (Sheet 2 of 3)



(C) Test Data at Failure of the CTSA Test Box

Fig. 79 Test Data (Sheet 3 of 3)

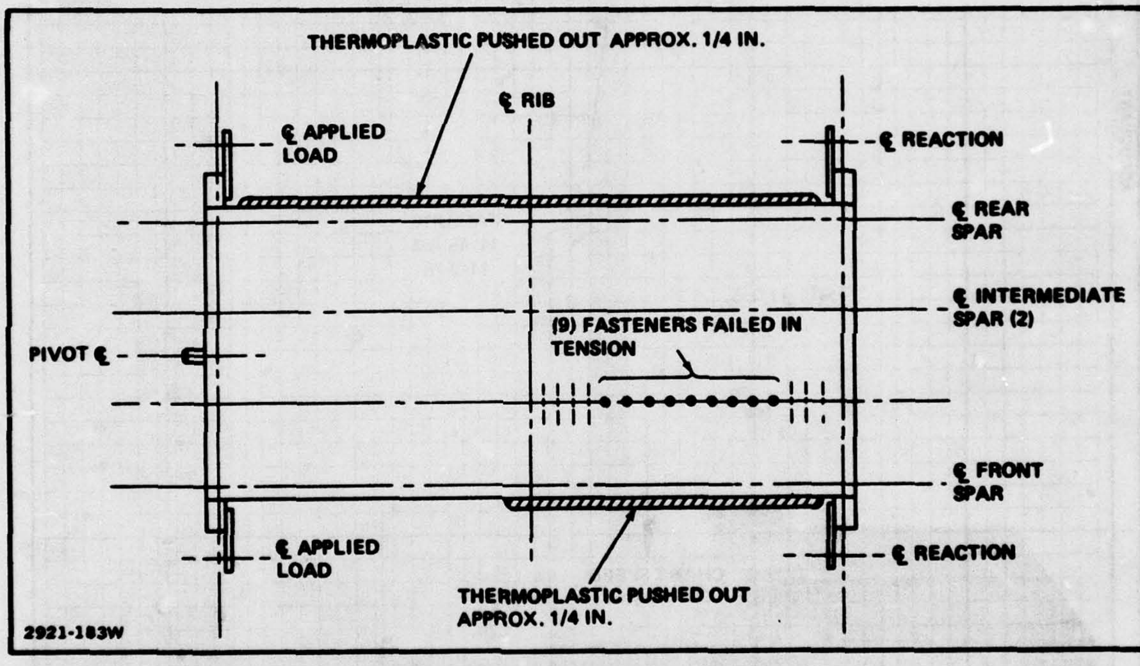


Fig. 80 CTSA Test Box Sketch of Failures

TABLE 15
COMPONENT DEFLECTION DATA

TEST CONDITION	SPECIMEN DEFLECTION, INCHES		
	LIMIT LOAD	125% LIMIT	DESIGN ULTIMATE (150% LIMIT)
Static Test - Limit Shear at RT	0.203	–	–
Static Test – Combined Limit Shear and Pressure at RT	0.201	–	–
Static Test – Combined Limit Shear and Pressure at 270°F	0.252	–	–
Fatigue Test – Combined Cyclic Limit Shear and Pressure at RT and 270°F	0.214 at RT 0.257 at 270°F	–	–
Static Failing Load Test – Combined Shear and Pressure at 270°F	0.246	0.316	0.386

2921-184W

The last test performed, test number nine, demonstrated the thermoplastic sealing technique employed on the test specimen. The results of this demonstration are presented in subsection 4.2.3.

6.7 FAILURE ANALYSIS OF SUBCOMPONENT

6.7.1 Introduction

As reported in Subsection 6.2, the subcomponent test box failed under the simultaneous application of the design ultimate torque and an internal pressure of 95.5 psi. Failure consisted of the inability to maintain internal pressure. Visual inspection revealed that nine of the C2R1868 fasteners that connect the upper cover to one of the intermediate spars had failed, allowing the pressurized oil to flow out of the box. X-ray inspection indicated delaminations in the bend radii of the spar caps at the upper cover-to-intermediate spar connection. No other structural damage was evident. The slight fluid weepage observed at the lower cover stitch line during the fatigue test of the box (Subsection 6.6) was also observed in a post-failure inspection of the test box assembly filled with water.

Because the designs of the connections of the upper and lower covers to the intermediate spars are identical to concepts tested in the element phase of the program, and because the test box was designed so that these areas would be critically stressed, an analysis of the test box failure would primarily rely on extrapolation of the element test results to the test box structural configuration. In this extrapolation, the analyst must consider the following:

- The element phase of the program involved evaluation of only the flatwise tension load carrying capability of the individual configurations, while in the test box assembly, the covers are subjected to spanwise and chordwise tension and in-plane shear loads. These forces can act to aggravate the stress state at the cover-to-spar connections caused by flatwise tension alone.
- In the element phase of the program, the flatwise tension load was reacted by concentrated loads at the rollers. In the test box, the flatwise tension load is counterblanaced by a distributed pressure acting on the cover, a somewhat less severe condition.

- Although most of the applied torque is carried through the front and rear spars, a shear flow of approximately 100 lb/in. is transmitted through the cover-to-intermediate spar connections.
- Prior to being statically loaded to failure, the test box had been subjected to the fatigue spectrum detailed in Subsection 6.5. The stress level and number of cycles involved in this spectrum are not considered high enough to significantly degrade the flatwise tension strengths of the subject configurations.

6.7.2 Upper Cover-to-Intermediate Spar Connection

The upper cover-to-intermediate spar connection configuration used in the test box assembly is identical to the mechanically attached angle cap specimens (D10B2001) of the element phase of the program. The three mechanically attached angle cap specimens tested in Phase I at 270°F (Dry) failed at an average load of 546 lb/in. The failure mode was delamination in the flange bend radius (see Subsection 3.4.4). One would not expect the addition of in-plane loads to the cover to affect the flatwise tension load carrying capability of this configuration. The reaction of the flatwise tension load by distributed pressure rather than concentrated roller loads results in a slightly less severe stress state in the flange bend radius, but this difference is considered insignificant. The shear force transmitted through the cover-to-spar connection is small and will be transmitted by the fasteners and should not detract from the ability of the joint to carry a flatwise tension load significantly.

The internal pressure at failure produced spar flatwise tension forces calculated to be 620 lb/in. Delaminations in the spar flange bend radii would be expected at this load and were observed in an X-ray inspection.

The load in the C2R1868 fasteners connecting the spar caps and upper cover was calculated to be 1330 lb at failure. The predicted failing load of these fasteners is 1190 lb (see Subsection 4.1.7), and as reported in the introduction, a post-failure visual inspection of the test box revealed that nine of these fasteners had failed as shown in Fig. 81.

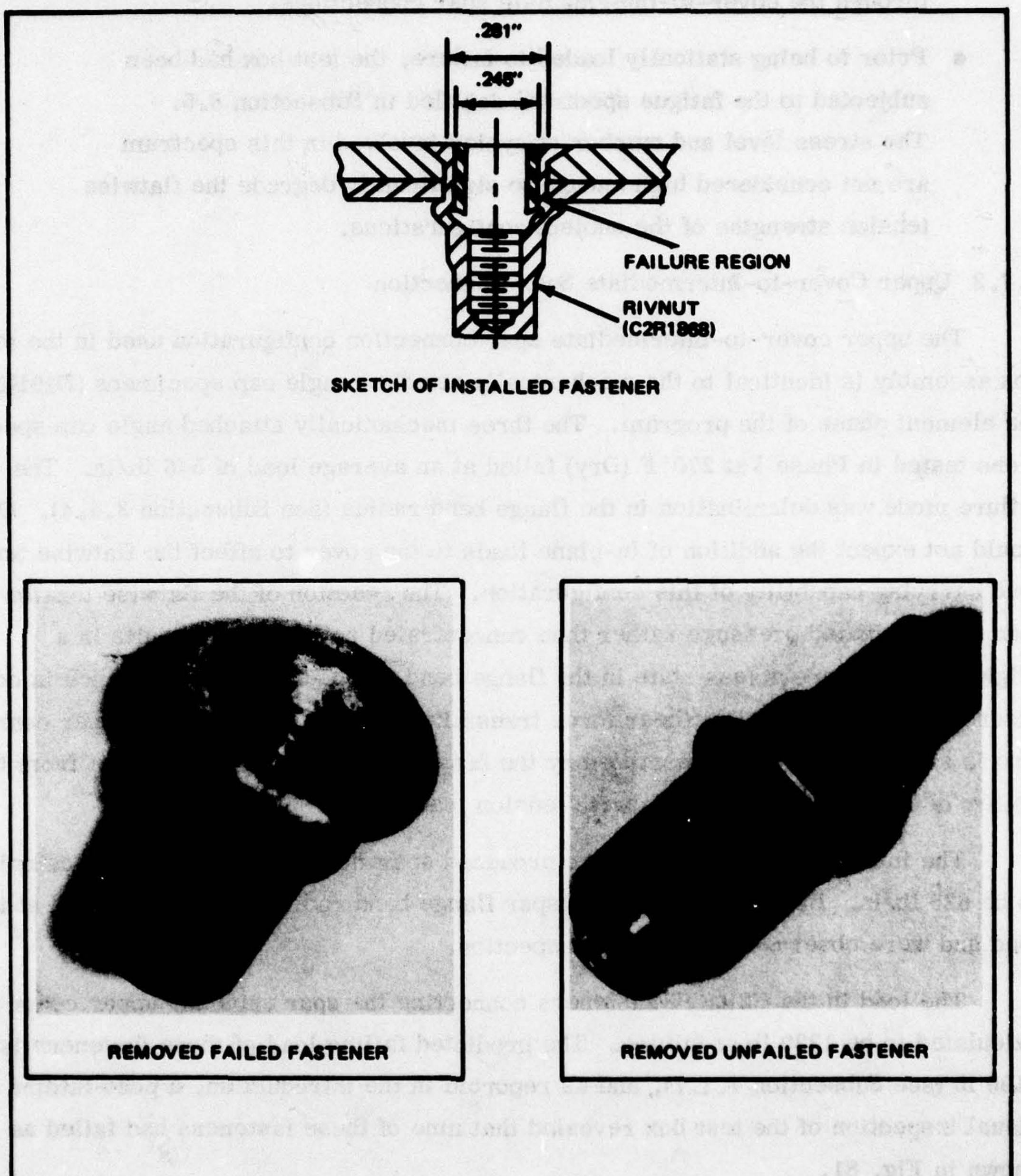


Fig. 81 Failed Fasteners

6.7.3 Lower Cover-to-Intermediate Spar Connection

The stitched cap angle configuration used to attach the lower cover to the intermediate spars is identical to the Concept I configuration (D10B2009-57), tested in the element phase of the program. The three Concept I specimens tested in Phase I at 270°F (Dry) failed at an average load of 785 lb/in. Bond failure under the heel of the flange occurred in these specimens at an average load of 488 lb/in. (see Subsection 3.4.1) but did not cause catastrophic failure of the specimens due to the presence of the stitching.

The presence of spanwise and chordwise tension and in-plane shear forces in the cover of the test box aggravates the stress state at the spar/cover bond line and should reduce the flatwise tension load required to cause initial bond failure from that obtained in the element tests. The shear flow carried through the cover-to-spar connection is carried through the bond and would also tend to reduce the flatwise tension load required to produce initial bond failure under the heel of the flange. On the other hand, the reaction of the flatwise tension forces by the distributed pressure results in a less severe stress state under the heel of the flange than when the flatwise tension is resisted by concentrated roller forces. The combined quantitative effect of these perturbations on the extrapolation of the element test results for initial bond failure to the test box assembly is difficult to assess. However, as previously noted, bond failure does not lead to catastrophic failure due to the presence of the stitching, and the ultimate strength of the stitched joint is essentially independent of the bond failure load.

Analysis of the test box indicates that the stitched joint successfully carried a flatwise tension load of 620 lb/in. when the upper cover fasteners failed. It is anticipated that the bond under the heel of the flange was failed at this load, but that crack propagation was prevented by the stitches. This could only be verified by a sectioning of the box. Ascertainment of the additional load carrying capability of the joint, over and above the 620 lb/in., was precluded by the fastener failure.

The weeping at the lower cover stitch lines observed in the fatigue test (see Subsection 6.6) was also observed in a post-failure inspection of the water-filled, unpressurized box. This seepage is likely due to matrix micro cracking in the immediate vicinity of the stitch caused by the cyclic three dimensional stress state

produced in the stitch/matrix interface region during the fatigue testing. High matrix shear and normal stresses arise at the stitch/matrix interface due to the strain mismatch which occurs when the stitch is stressed by the flatwise tension loads in the spar. In addition, high matrix stresses are generated around the stitch as the cover bending, axial, and shear loads bypass the stitch "hole". Note that the total volume of fluid leaked during the fatigue test was only 3.2% of the total test box volume and only a small portion of this 3.2% was leaked at the stitch lines. In any event, the stitch leakage problem is easily obviated by design procedures detailed in the Conclusions and Recommendations presented in Section VII.

SECTION VII

CONCLUSIONS AND RECOMMENDATIONS

The objectives of this program have been achieved:

- **To develop and test wing designs and manufacturing concepts that will eliminate the need for fasteners to attach the lower wing cover to the substructure**
- **The evaluation of thermoplastic adhesives to provide a repairable fuel sealing concept for wing structures**
- **The demonstration of the removal and reinstallation of the upper cover.**

The significant results attained in the program are summarized below:

- **The design, fabrication and successful test of integrally cured graphite/epoxy cover to spar concepts both sewn and unsewn**
- **The verification by test of the increased structural efficiency of the sewn concepts both in strength and in the failure mode (damage tolerant)**
- **The development of graphite/epoxy sewing manufacturing technology for thicknesses up to 90 plies of graphite/epoxy**
- **The design, manufacture and test of translamina reinforced spar caps using through the cover graphite tows**
- **The integral curing of mechanically fastened intermediate spars with the upper cover using a separator between the spar flange and the cover, thus eliminating the liquid shimming operation**
- **The design, manufacture and test of front and rear spars with integral ends (bathtub type)**
- **The design, manufacture and test of a sewn/integrally cured lower cover assembly**

- The demonstration of interference fit fasteners for fuel sealing purposes in graphite/epoxy structures
- The design, manufacture and test of a thermoplastic sealing concept which has the promise of resealing by applying local heat
- The demonstration of material and labor cost savings offered by sewn/integrally cured cover/spar joints
- Verification of the ability of a sewn/integrally cured cover/spar joint to resist a flatwise tension load of 620 lb/in. in conjunction with cover passing loads of N_{xy} = 1200 lb/in. and $N_x = N_y$ = 230 lb/in. at 270°F. This was demonstrated after the text box had been subjected to 10,000 fatigue cycles (9000 at RT, 1000 at 270°F) of 800 lb/in. shear and 25 psi pressure.

It must be emphasized that all tooling and fabricating concepts were demonstrated for flat panels. In addition, the sewing technology work was only experimental in nature. It is recommended that the applicability of the developed sewn/integrally cured processes and tooling methods to the fabrication of single and compound curvature structures be investigated. In addition, the subcomponent test box was loaded only by a torque and internal pressure and it is recommended that the introduction of wing bending loads combined with torsion and internal fuel pressure be investigated.

The weeping experienced by the stitches during the fatigue test and later during the thermoplastic adhesive leak check can easily be resolved in future fuel tight sewn assemblies by adding graphite/epoxy plies over the stitch line prior to final cure or by adding a bead of fuel sealant over the stitches during assembly.

The use of interference fit fasteners for fuel sealing purposes in the subcomponent test box was successful. It should be noted that the shear load in the bolt was small and that the cover load intensity (N_x) was also small. Therefore, it is recommended that further testing, specifically of a loaded hole combined with cover passing loads, be performed using interference fit fasteners.

The thermoplastic adhesive was proven capable of sealing a fuel tight wing box. However, further development is required in the design and manufacture of graphite/epoxy heating elements if uniform heating throughout the entire length of the adherends is to be achieved.

REFERENCES

1. Kuhn, P. "Stresses in Aircraft and Shell Structures," McGraw Hill, 1956.
2. "Graphite/Epoxy and Boron-Graphite/Epoxy Hybrid Design Allowables," ADR 11-04-77.1, Grumman Aerospace Corporation, March 1977.
3. Second Quarterly Report "Advanced Composite Wing Cover-to-Substructure Attachment (CTSA) Development Program, Grumman Aerospace Corporation, 15 February 1978.
4. Sechler, E.E., "Elasticity in Engineering," John Wiley and Sons, Inc., N.Y., 1952.
5. "Allowable Stresses for Graphite/Epoxy and Hybrid Boron-Graphite/Epoxy Laminates with Open Holes," ST MECH 040, Grumman Aerospace Corporation, July 1978.
6. Chalus, R.J., "Structural Test Plan For Cover-to-Substructure Attachment Test Box," Revision A, AC-ST-8105, Grumman Aerospace Corporation, 9 June 1978.

*U.S.Government Printing Office: 1979 — 657-002/513